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No. 1

STRENGTH PROPERTIES OF CAST IRON PIPE MADE BY DIFFERENT PROCESSES AS FOUND BY TESTS¹

BY ARTHUR N. TALBOT²

The purpose of this article is to report results of tests by flexure, impact, and internal pressure made on 6-inch cast iron pipe and on auxiliary test specimens and to discuss their bearing on the properties of cast iron pipe and on possible requirements for the thickness, uniformity and quality of such pipes as made by different processes. The information was obtained in an investigation made for the following manufacturers of cast iron pipe: American Cast Iron Pipe Company, Glamorgan Pipe and Foundry Company, Lynchburg Foundry Company, Donaldson Iron Company, Warren Foundry and Pipe Company and R. D. Wood and Company.

In considering qualities needed in cast iron pipe it is evident that as the purpose of the pipe is to hold the water or other contained material under pressure, the resistance of the pipe to internal pressure (bursting strength) is very important. Granted that the thickness of the pipe is sufficient to sustain external loads that may come upon it, either static or impact loads, and that the metal is durable for the conditions of use, the information that is given by an internal pressure test of single lengths of pipe on their tensile strength and

¹ Presented before the Buffalo Convention, June 9, 1926.

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the nature of their failure should be of high value and usefulness. It is usually assumed that the strength found by tests of the metal such as that made on the standard test bar, gives information applicable to the determination of the pressures which a pipe will withstand, but, of course, the numerical relation of the modulus of rupture to the tensile strength of the metal in the pipe must be known before the bursting strength may be judged in this way with even fair accuracy. It seems that there is relatively little information available on the relation between results of test specimens and the bursting strength of pipe, and also very little on the relation between the longitudinal and the circumferential strength of the metal in the pipe. The usual proof test, as ordinarily conducted, may not be expected to do more than find whether there are glaring defects in the pipe, defects that might show up at once after the pipe is put into the ground, and so such a test has little value on what thickness should be given to pipe or on what qualities the pipe has. That pipe which will pass the ordinary proof test may vary greatly in quality is shown in tests herein reported where pipe of one thickness failed at an internal pressure less than twice the usual proof test and others in the same lot made by the same process carried ten times that proof pressure before failure. Of other tests, it may be expected that the breaking of a pipe in flexure will give information on loads that may be carried by the pipe and may give data on the quality of the pipe, especially if flaws or defects develop. An impact test may be of value in helping to judge of the resistance to blows received in handling and may also bring out the properties of the metal in the pipe.

It must be accepted that there will be uncertainties and imperfections in cast iron pipe, although, of course, these vary according to the conditions of manufacture. The metal itself may vary in quality. There is possibility of spots of inferior metal. Variations in thickness around the circumference of the pipe and from end to end lead to increasing the specified thickness and to giving a relatively large tolerance in thickness. As a result of these uncertainties and the possibilities of variations in thickness and in quality of metal the adopted standard thicknesses are necessarily considerably greater than would be needed if the pipe were of uniform dimension and quality, or even if the actual conditions of the product were fairly accurately known. With new processes of manufacture coming into use it is important to know whether one process of manufacture is freer from imperfections and uncertainties of a given kind than

another and what feature of inspection is especially needed in judging of the pipe of any given process. Then too, it is desirable to have information on the meaning of the tests of auxiliary test specimens which may be made in connection with inspection as related to the products of a given method of manufacture.

The investment in the distribution system of a water works plant bears such a large proportion to the total investment that too much consideration can not be given to the quality and to the design of the cast iron pipe used in the system. It is hoped, therefore, that the information given in this paper will be of some value in throwing light on the strength qualities of cast iron pipe and on their uncertainties and imperfections, and also on the usefulness of the several tests which may be made in connection with the manufacture of the pipe.

Part of the pipe used in the tests were bought in the market and part were furnished direct by manufacturers. In all more than 300 pipes were tested. The following processes of manufacture were represented by lots of pipe: (a) the common process of casting vertically in dry sand mould and core, the lots included in groups I and V; (b) casting horizontally in green sand mould and core, the lots in group IV; (c) casting by a centrifugal process in refractory mould, the lots in groups II and VI; and (d) casting by a centrifugal process in water-cooled metal mould, the lots in group III. The numbers given to the lots of pipe in each group are recorded in table 1, as well as the manufacturers of the pipe. The sand-cast process is the common one and does not need description. The pipe of group IV were cast horizontally with green sand mould and core, pouring gates being spaced about 6 inches apart along one side of the pipe. In the centrifugal process used in the manufacture of the pipe of group II and VI a metal flask containing an open green sand mould (without core except for the head core) is slowly rotated in a position slightly inclined from the horizontal and the molten metal is poured in at the upper end. During the charging the machine is brought to a horizontal position, and after completion of the charging is made to rotate very rapidly, continuing until the metal has solidified. In the centrifugal process used in the manufacture of the pipe of group III a metal mould is used (without core except for the head core), which is water-cooled. The mould in a position slightly inclined to the horizontal is rotated rapidly and the molten metal is poured into the mould through a cantilever runner which delivers the metal first at the far end, the mould being with-

TABLE I
Data of cast iron pipe tested

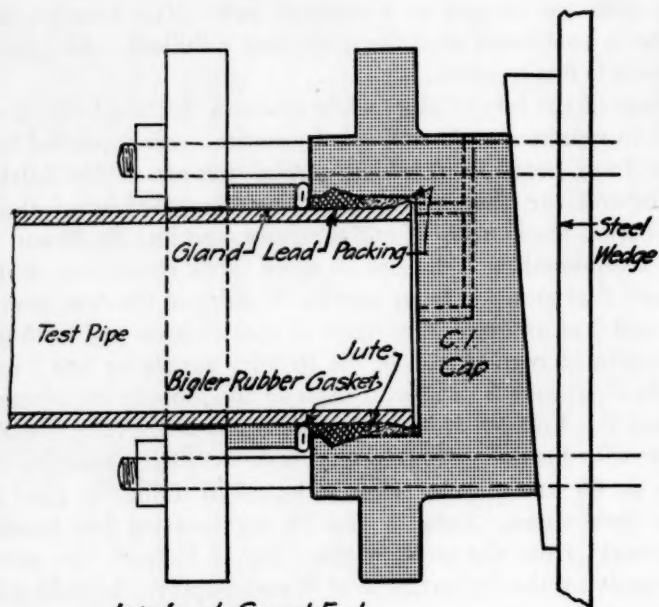
GROUP	PROCESS OF MANUFACTURE	DESCRIPTION OF PROCESS	LOT	FOUNDRY	SOURCE
I	Sand-cast	Pipe cast vertically in dry sand mould and core	1	A. C. I. P. Co.	From manufacturer
			4	A. C. I. P. Co.	From manufacturer
			20	Lynchburg F. Co.	From manufacturer
			30	Warren F. & P. Co.	From manufacturer
			40	J. B. Clow & Sons	From manufacturer
			70	National C. I. P. Co.	From dealer
			71	J. B. C. and S.	From Chicago
II	Centrifugal	Centrifugal process in refractory (sand) mould	72	U. S. C. I. P. & F. Co. Addyston	From Chicago
			73	U. S. C. I. P. & F. Co. Bessemer	From Detroit
			A	A. C. I. P. Co.	From manufacturer
			B	A. C. I. P. Co.	From manufacturer
			F	A. C. I. P. Co.	From manufacturer
			75	A. C. I. P. Co.	I. P. & L. C.
III	Centrifugal	Centrifugal process in water-cooled metal mould	50	U. S. C. I. P. & F. Co.	From manufacturer
			51	U. S. C. I. P. & F. Co.	From manufacturer
			52	U. S. C. I. P. & F. Co.	From manufacturer
			74	U. S. C. I. P. & F. Co.	From Detroit
IV	Sand-cast	Pipe cast horizontally in green sand mould and core	60	McWane C. I. P. Co.	From manufacturer
			76	McWane C. I. P. Co.	From dealer
V	Sand-cast	Pipe cast vertically in dry sand mould and core	2	A. C. I. P. Co.	From manufacturer
			3	A. C. I. P. Co.	From manufacturer
			5	A. C. I. P. Co.	From manufacturer
VI	Centrifugal	Centrifugal process in refractory (sand) mould	C	A. C. I. P. Co.	From manufacturer
			D	A. C. I. P. Co.	From manufacturer
			E	A. C. I. P. Co.	From manufacturer

drawn from the runner at a uniform rate. The rotation of the machine is continued until the metal has solidified. An annealing treatment is finally given.

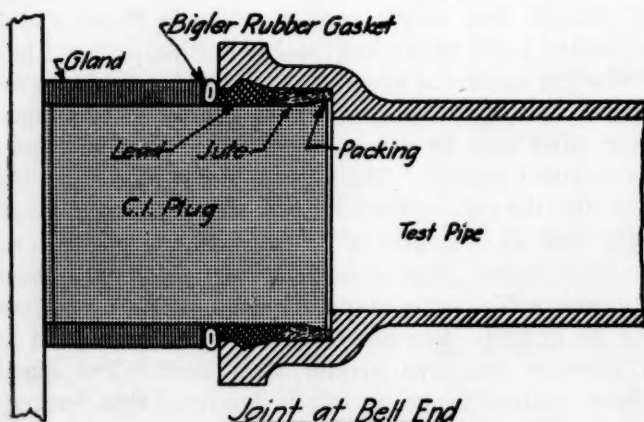
Certain of the lots of pipe, while made in the usual way and intended to represent ordinarily good practice, were furnished by the makers from heats from which careful records of the mixtures, temperatures, etc., had been kept. These included lots 1 and 4 of group I from the foundry of one company, and lots 20, 30 and 40 of group I representing foundries of three other companies, and lots A, B and F of group II from another foundry of the first company. Lot 2 and 3 of group V were made of special irons and lot 5 of 16-foot lengths of regular iron in the foundry supplying lots 1 and 4, and lots C, D and E of special irons in the foundry supplying lots A, B and F. Lots 50, 51 and 52 were bought direct from the manufacturer with the understanding that tests were to be made on them, as was lot 60, and may be taken to represent ordinarily good practice in their shops. Lots 73 and 74, representing two foundries, were bought from the stock of the City of Detroit, the selection being made by the Department of Water Supply. Lots 71 and 72 were bought from the stock of the Department of Public Works of Chicago and lot 70 from the stock of a Chicago dealer, three foundries being thus represented; the selection in these cases was made by Mr. Richart. Lot 75 was bought from the Illinois Power and Light Corporation and lot 76 from a local supply in Birmingham, Alabama. It is felt that the method of selection of the lots bought in the market was such that the pipe so secured may be considered to represent in a fair way what may be expected from a random selection from stocks of excellent quality. The random lots of pipe were obtained and tested after the tests on the other lots of pipe had been completed.

The pipe were all in lengths of 12 feet, except lot 5 which was 16 feet. At least twelve pipes of each lot were obtained. Generally, three pipes were subjected to internal pressure, three to cross-bending, and three to impact. For several lots the number tested in the internal pressure test was greater than three. The remaining lengths were retained for use in case it developed that further tests were needed. The pipes were tested at random—no single lot being tested seriatum.

The following tests of the pipes were made: internal pressure tests, flexure tests, and impact tests. The following test specimens were cut from pipe: rings, two forms of tension specimen, and strips



Joint at Spigot End



Joint at Bell End

FIG. 1. CAP AND PLUG USED IN INTERNAL PRESSURE TEST

for tests in flexure. For several lots of pipe standard test bars poured at the time a lot of pipe was cast were available.

INTERNAL PRESSURE TEST OF PIPE

In the internal pressure test the pipe was placed in a restraining frame, filled with water, and then subjected to internal hydraulic pressure, which was gradually increased until failure occurred by the fracture of the pipe.

Special cast iron plugs and caps were provided for closing the two ends of the pipe. The solid cast iron plug (see fig. 1) 9 inches long and 6.9 inches in diameter, with a bead at the end similar to a pipe bead, was fitted into the bell of the pipe, two layers of hemp packing and two layers of soap-treated jute packing calked in, and lead run into the remaining joint space and calked exceptionally hard. A well fitting gland of cast iron was placed over the other end of the

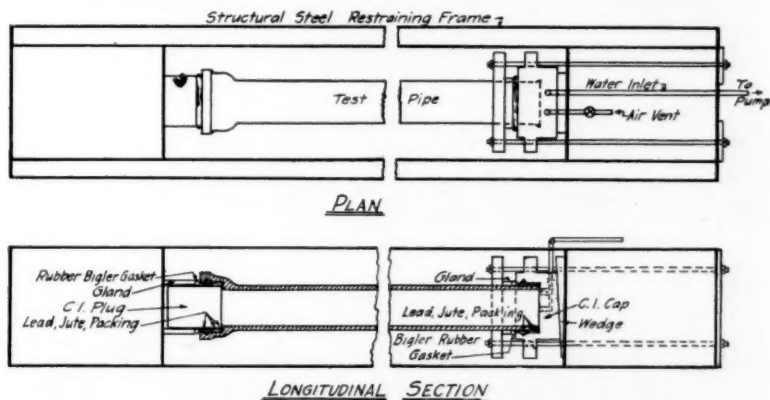


FIG. 2. APPARATUS USED IN INTERNAL PRESSURE TEST

plug, with a Bigler rubber gasket between gland and lead packing. The cast iron cap of the form shown in figure 1 was calked to the spigot end of the pipe in a similar way. The head end of the cap has a bevel of 1 in 15, and a wedge of the same slope fits in front of it. A flange or ring encircling the pipe carries four bolts, which pass also through the end of the restraining frame, the tightening of the bolts pushing the cast iron gland and the Bigler rubber gasket firmly against the lead packing. Great care was required in forming these joints. As indicated in figure 1 the cap has drilled passage ways to permit the entrance of water and the discharge of air. Four sets of these end closing devices were available, and the work of calking the joints did not interfere with the progress of making the internal pressure tests.

The pipe was then placed in a heavy structural-steel holding or restraining frame built by the American Cast Iron Pipe Company for the purposes of the test, which is sketched in outline in figure 2, with a view in figure 3. This frame took the end thrust from the pressure on the plug and cap, a force that may have amounted to 100,000 pounds in some cases in these tests. This thrust caused tension in the sides of the restraining frame, which consisted of built-up plate and angle sections so designed as to develop very low working stresses when the 6-inch pipe was tested. The two ends of the

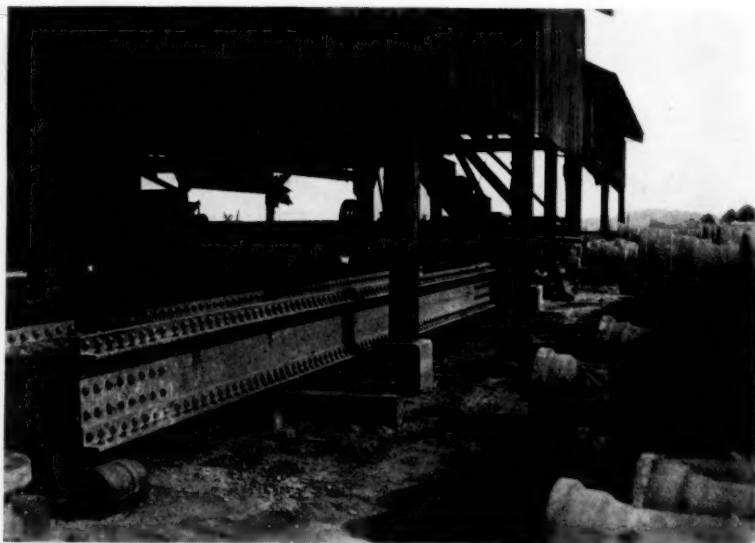


FIG. 3. VIEW OF RESTRAINING FRAME

frame, which received the thrust from the cap and the plug consisted of very stiff diaphragms formed of I-beams and plates.

The arrangement of the pipe in the restraining frame was such that as the internal pressure was applied a sufficient movement of the plug was provided for to allow the pressure on plug and cap to be transmitted directly to the stiff restraining frame. The lead joints, however, were held tightly in their initial positions in the cap and in the bell of the pipe by means of the cast iron packing rings or glands bearing on the exposed face of the joints. As it was found that the machined cast-iron plug would move outward slightly within the lead joint of the bell at quite low pressures and without causing

leakage, it is evident that a pipe tested in this apparatus was practically free from longitudinal tension and was also fairly free to shorten in length as it stretched circumferentially under the internal pressure. The existence of this condition was verified by measurements of strain on 2-inch gage lines in a circumferential direction and on 8-inch gage lines in a longitudinal direction that were made on a number of the pipes tested.

In testing, the pipe was filled with water from a main carrying a pressure of about 400 pounds per square inch admitted through an opening at the top of the cap, another opening in the cap permitting the discharge of air. Higher pressures were applied by means of a motor-driven triplex pump. Pressures were read by the use of a hydraulic gage placed in the line between pump and test pipe, and compared at frequent intervals with a second gage that had been carefully calibrated with a Crosby fluid pressure scales. The gages indicated that the pressures increased quite steadily and that there was very little surging effect produced by the strokes of the pump. Since any leakage was very troublesome due to the size of the feed line from the pump great care was taken to secure tight joints. Generally, when a pressure of 1000 pounds per square inch was reached, pumping was stopped and the packing glands were again tightened against the lead joints by driving down the wedge and sometimes tightening the bolts further. With these precautions there was little or no leakage. In the case of three or four pipes leakage was troublesome and the joints were melted out and remade.

Failure was always sudden. It is worth noting that the fracture of every pipe occurred at the part of the circumference and the portion of the length that had the least thickness of wall. The pipe generally failed by the formation of a longitudinal crack, which opened only slightly. Of groups I and V, in about half the tests a single longitudinal crack formed extending from 3 to 5 feet in length, sometimes branching at its ends, but no piece being broken from the wall. In the other half of these pipes one or two pieces 9 to 15 inches long and 3 to 5 inches wide, broke out at one end of the crack, and in two cases at both ends of the crack. The cracks were longer in the pipes of groups II and VI, extending about 5 to 7 feet in half of them and nearly the full length of pipe in the others. In four of these a single small piece was also broken out of the pipe. The pipes of group III gave an entirely different fracture. Lots 51, 52 and 74 broke up into from five to thirty pieces, irregular in form, and

Internal pressure test of pipe

Dimensions are given in inches, weights in pounds, pressure and strengths in pounds per square inch and deviations in per cent of the average strength of each lot.

[illegible]

[illegible]

TABLE 2—*Concluded*

LOT	PIPE NUMBER	WEIGHT OF PIPE	THICKNESS AT BREAK	BURSTING PRESSURE	BURSTING STRENGTH	AVERAGE BURSTING STRENGTH	MEAN DEVIATION
Group VI							
C	1A	375	0.44	3,380	22,800	22,100	5.1
	3A	360	0.41	3,150	23,000		
	5A	365	0.42	2,860	20,400		
D	1A	345	0.38	2,810	22,200	20,500	7.9
	3A	360	0.40	2,860	21,300		
	7A	345	0.42	2,520	18,100		
E	3A	340	0.33	2,570	23,800	24,900	2.9
	5A	325	0.32	2,620	25,000		
	7A	325	0.33	2,810	25,900		
Average—group VI.....						22,500	5.3

* The pipes of lot 5 are 16-foot lengths, all others are 12-foot lengths.

generally sharp-pointed, nearly always having a spiral form of fracture, the lines of the spiral being at angles that would require 4 or 5 feet to extend around the pipe once. Lot 50, which developed a considerably lower tensile resistance, did not shatter so badly.

After the test the pipe was broken up with a sledge and measurements of thickness were taken at each end of horizontal and vertical diameters for five sections along the length of the pipe. Measurements of the thickness were also made at several points along the line of fracture, and the general thickness so found was recorded as the "thickness at break."

Table 2 gives the results of the internal pressure tests. The bursting strength or tensile resistance against internal pressure reported in the table was calculated from the internal pressure at failure (with gage reading corrected to standard), the inside diameter of the pipe, and the "thickness at break," using the formula $S = \frac{pd}{2t}$, where S is the tensile resistance in pound per square inch, p the internal pressure in pound per square inch, d the inside diameter of pipe in inches, and t the "thickness at break" in inches. It is seen from the table that the bursting strengths of the pipes of a lot do not differ greatly from their average, as is also indicated by the values of the percentage of mean deviation from the average. It will be noted that the bursting strength of one group differed from that of another.

One pipe of lot 71 which proved to have a thin spot for 18 inches of its length near the bell end (more than 25 per cent thinner than

the average thickness) gave a bursting strength of 10,500 pounds per square inch based on the thickness at the thin spot where the break occurred, and was omitted from the table. Two pipes of lot 50, with no apparent flaws, gave bursting pressures of 570 and 670 pounds per square inch and corresponding bursting strengths of 5400 and 7000 pounds per square inch, and also were omitted. One pipe of lot 2 proved to have a thin spot and one of lot D a thin section; the use of the dimension of the thin portion gave bursting strengths so abnormally high that these pipes also were omitted.

FLEXURE TEST OF PIPE

The flexure or cross-bending test was made by applying load on the pipe at the middle of a span of 10 feet, the supports being approximately symmetrical with respect to the full length of the pipe. Rocker supports were used, the rocker having a radius of 10 inches and the knife edges, $1\frac{1}{4}$ inches. The load was applied through a similar knife edge. The deflection of the pipe during the test was measured with a precision of $\frac{1}{1000}$ inch. For every load the external vertical and horizontal diameters of the pipe were also measured at a section about 3 inches from the mid-span. Generally the measurements were taken at each 1000 pound of load up to and including the one next to the load of failure. The load was applied at a nominal rate of 0.22 inch per minute.

The pipe always failed very suddenly without previous cracking noises or other warning. Generally speaking, it was found that when a load gave a greatly increased rate of deflection, failure occurred within another 1000 pounds. Generally the pipe broke straight across, the fracture being clean-cut and almost square and otherwise generally having the lines of the fracture all within 2 inches of the mean section of the break. A few broke with a fracture somewhat more oblique. The fracture generally occurred at one side of the load point, generally within 5 to 8 inches of it. In five cases of group III there were two fractures, one on each side of the load point, a piece of the pipe 15 to 22 inches long thus being broken out. In several cases in this group a longitudinal crack a few inches long was formed through the top wall of the pipe at and near the load point a little time before failure occurred.

Table 3 gives the results of the flexure tests. Only the average maximum load and average modulus of rupture of a lot of pipe are reported, but it is seen from the values of the mean deviation of the

TABLE 3
Flexure test

Dimensions are given in inches, loads in pounds, strength in pounds per square inch, and deviations in per cent of the average strength for each lot.

GROUP	LOT	NUMBER OF PIPES	THICKNESS AT BREAK	AVERAGE MAXIMUM LOAD	AVERAGE MODULUS OF RUPTURE	MEAN DEVIATION
I	1	3	0.53	15,920	29,000	3.8
	4	3	0.51	16,830	32,200	6.4
	20	3	0.50	13,920	27,000	2.2
	30	3	0.47	13,220	26,800	0.7
	40	3	0.50	15,970	29,300	7.1
	70	3	0.53	15,970	28,400	5.3
	71	3	0.50	14,030	26,300	2.7
	72	3	0.52	14,730	26,900	6.5
	73	3	0.55	15,530	26,800	4.9
Average.....					28,100	4.4
II	A	3	0.46	17,850	39,500	2.4
	B	3	0.42	12,730	30,700	3.5
	F	3	0.46	17,340	37,500	4.4
	75	3	0.46	17,700	38,600	8.5
Average.....					36,600	4.7
III	50	6	0.35	13,130	34,500	5.8
	51	6	0.37	12,660	32,200	6.5
	52	6	0.39	15,450	37,000	12.2
	74	3	0.41	18,230	42,700	4.3
Average.....					36,600	7.2
IV	60	6	0.40	13,570	33,100	8.1
	76	5	0.39	14,960	36,100	4.7
Average.....					34,600	6.4
V	2	3	0.50	15,430	29,900	0.3
	3	3	0.47	18,090	36,100	1.7
	5	2	0.51	17,170	31,700	1.6
Average.....					32,600	1.2
VI	C	3	0.48	18,980	38,700	3.8
	D	3	0.48	17,580	36,800	4.9
	E	3	0.48	20,390	41,800	2.0
Average.....					39,100	3.6

modulus of rupture from the average for a lot, as given in the table, that the individual pipes of a lot did not generally differ greatly from the average of the lot.

The modulus of rupture was calculated from the formula $S = \frac{Plc}{4I}$

where S is the modulus of rupture, P the breaking load, I the moment of inertia of the section, l the span length and c the distance from the neutral axis to the remotest fiber in tension. For this purpose the moment of inertia of a section was calculated from the properties of two circular areas, an outside and an inside circle which gave the measured thickness of wall at the top and bottom of the pipe at the section of fracture, and not from the thickness at break given in the table. The neutral axis was determined in a similar way. The distance from the neutral axis to the extreme fiber in tension so found was used for the c of the formula. This method, of course, is approximate and empirical, but as the variations in the thickness of the pipe at the different parts of the section were relatively small and the pipe was placed in the testing machine just as it happened to come, this method of calculation may be expected to give results that are properly comparative.

Measurements of outside diameter of pipe under load made at sections along the length on one pipe of lot A having an average thickness of 0.46 inch showed a decrease in vertical diameter at the load point of 0.04 inch for a load of 16,000 pounds, the decrease in diameter at a section 12 inches away being only 10 per cent of this. For one pipe of lot 50 with thickness of 0.35 inch the corresponding decrease with a load of 12,000 pounds was 0.06 inch at the load point and 10 per cent as much at a section 24 inches away. It is evident that the length of pipe having considerable change in diameter due to the pressure of the load is shorter for the thicker pipe. In general the measurements taken at the load point on most of the pipe tested show that the increase in horizontal diameter at this section was less than the decrease in vertical diameter, the difference ranging from 12 to 30 per cent.

It is believed that the use of two-point loading in the flexure test would be an improvement, the loads being applied equally at the one-third points of the span. This load develops equal bending moments throughout the middle third of the length and thus the maximum stresses are developed over a considerable length of pipe. It is in common use in testing reinforced concrete beams and other structural members.

IMPACT TEST OF PIPE

For the impact tests an impact pipe testing machine was built by the American Cast Iron Pipe Company according to plans approved by the writer. The pipe was placed on two supports, filled with water, kept under the water pressure of the distribution main during the test (generally about 65 pound per square inch), and subjected to blows of the hammer dropped from increasing heights until a crack became apparent through a leakage of water.

The general arrangement of the impact testing machine is shown diagrammatically in figure 4 and from photograph in figure 5. The pipe rested on two supports 10 feet apart attached to a cast iron base 14 feet long and weighing about 2000 pounds which was embedded in the ground. The supports were recessed to receive the pipe which was held tightly in place by means of a clamp at each support.

The 50-pound hammer, falling between vertical guides, was arranged to strike the pipe at midspan. It carried as its striking edge a hardened steel bar $\frac{1}{2}$ inch wide by $1\frac{1}{2}$ inches deep by 4 inches long, with its lower edge slightly rounded. The low center of gravity of the hammer (obtained by loading with lead to get the desired weight) and the large ratio of vertical to horizontal distance between the contacts with guides served to minimize friction and to produce uniform and consistent behavior of the machine. The uniformity of action was studied by subjecting a piece of cold-rolled shafting to blows of the hammer and noting the uniformity of the indentation produced in the shafting. These tests were repeated each day and showed an average variation from the mean indentation of 2 to 3 per cent, which was considered a very satisfactory performance.

Before a pipe was placed in the testing machine, rubber discs were clamped in close contact over the two ends by means of a bolt passing through the length of the pipe, an arrangement that gave a tight connection for the water pressures used.

In making the test the first blow was made at a height of 6 inches. The succeeding applications were made with increments of height of 6 inches, the greatest height of drop permitted by the machine being 5 feet. As the hammer was dropped from increasing heights, failure was noted when a leak or spray of water came through the pipe. Generally an additional blow was applied after the one causing failure. The pipe was finally broken up with a sledge and measurements were taken of the thickness of walls.

In figure 6 the average height of drop for each lot of pipe has been plotted against average thickness of wall at the cross section at point of failure.

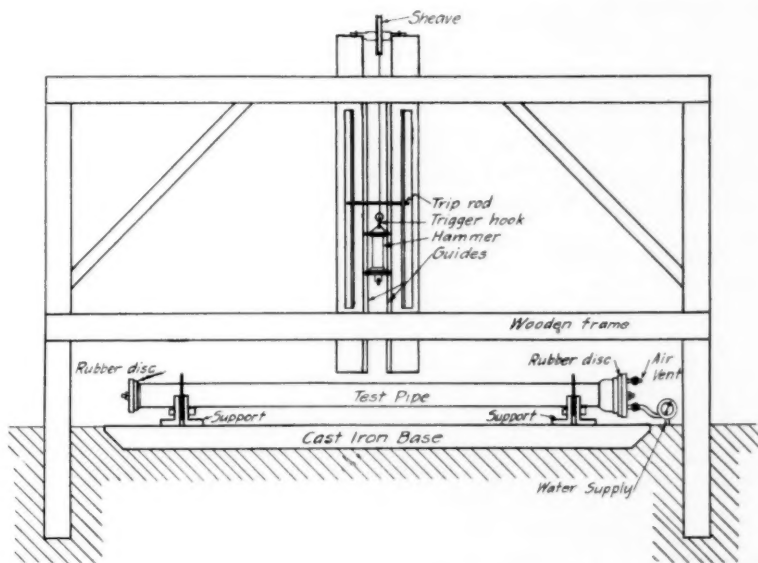


FIG. 4. IMPACT TESTING MACHINE

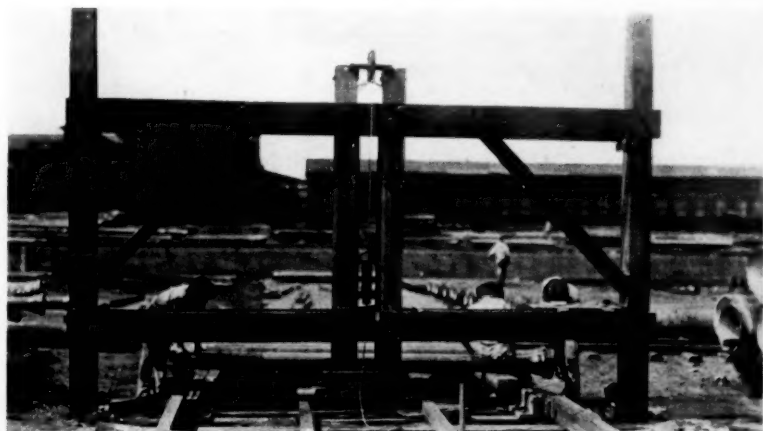


FIG. 5. VIEW OF IMPACT TESTING MACHINE

In every case the failure of the pipe became apparent through the formation of a crack that ran longitudinally along the top of the

pipe for a length of 1 to 12 inches (in one pipe to 36 inches). In about half of the tests the crack extended on both sides of the point where the hammer struck and in the other half on only one side or the other of this point. It is evident that the failure was due to flattening of the cross section of the pipe at its top and the breaking of the wall by bending inwardly. The crack would form first at the under side of the top wall of the pipe under this bending, and thus the crack may not have become apparent at the blow at which it started, but was observed when it was carried entirely through the wall and the water spurted through the opening.

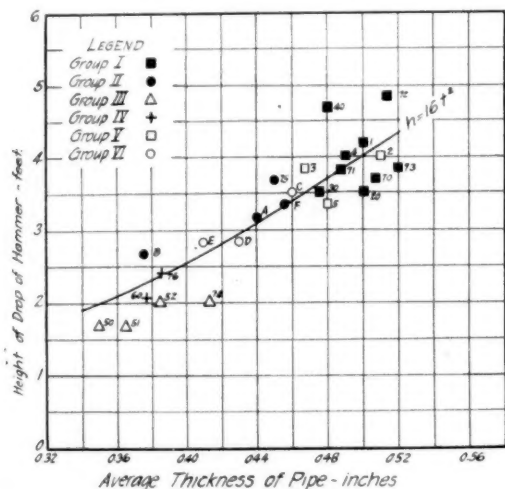


FIG. 6. THICKNESS OF WALL OF PIPE AND HEIGHT OF DROP IN IMPACT TEST

After the impact tests here reported had been studied, it was concluded that the impact testing machine should be modified by making the distance between centers of supports 2 feet and arranging it so as to permit testing a pipe at several points along its length. Tests made on 40 pipes near the middle, bell end, and spigot end show that the test in the new form is an improvement over the original. It permits finding whether one part of a pipe is weaker than another and eliminates many of the uncertainties of the relation between the energy of the blow, the inertia and deflection of the pipe, and its resistance to impact. The test is more severe, and increments of drop of 3 inches were used. The results are not ready for presentation, but the curve of results for a group was somewhat flatter, perhaps a curve of the three-halves power.

AUXILIARY TESTS

The auxiliary test specimens, the method of testing, and the test results are given below.

a. *Standard pipe test bar.* For the lots of groups I, II, V and VI not bought in the market, standard pipe test bars, 2 by 1 by 26 inches (see fig. 7, a), were made when the pipes were poured. These conform to the A. W. W. A. Standard. The metal was poured into the top of the vertical dry sand moulds. Generally six test bars were made, representing metal used at different times in the pouring of the pipes of one lot, but the number varied from four to nine. The

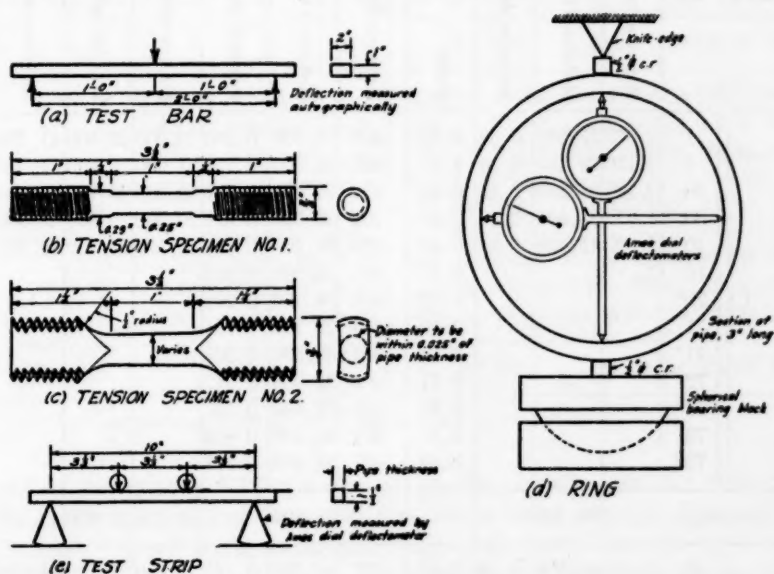


FIG. 7. AUXILIARY TEST SPECIMENS

test bars were tested flatwise with load in the middle of a 24-inch span. An autographic load-deflection diagram was obtained. Flaws and other defects that appeared were noted.

A summary of the results of the tests is given in table 4. The modulus of rupture was calculated in the usual manner. The loads and the deflections recorded in the table are modified values which correspond to an exact 1 by 2 inch cross-section.

b. *Tension test specimen no. 1.* Of the test specimens cut from the walls of the pipe, tension test specimen no. 1 (see fig. 7, b) was $3\frac{1}{2}$ inches in extreme length, threaded at the ends, and turned down to a

diameter of $\frac{1}{4}$ inch for a length of about 1 inch. The axis of the specimen coincided with the middle of the wall of the pipe. Three specimens were cut from one pipe that had been tested in flexure for each

TABLE 4

Results of tests of auxiliary test specimens

Loads are given in pounds, dimensions in inches, and strengths in pounds per square inch.

GROUP	LOT	TEST BAR			TEST STRIP				TENSION TEST		RING
		Maximum load	Modulus of rupture	Maximum deflection	Width	Maximum load	Modulus of rupture	Maximum deflection	No. 1 strength	No. 2 strength	
I	1	2,070	37,200	0.30	0.50	436	35,300	0.200	23,200	23,500	41,200
	4	2,170	39,100	0.34	0.51	491	38,300	0.226	21,600	25,400	37,500
	20	2,160	38,200	0.35	0.44	371	33,900	0.187	20,300	20,100	41,900
	30	1,970	35,400	0.31	0.48	402	33,700	0.216	20,200	19,800	38,300
	40	2,520	45,400	0.38	0.46	450	39,100	0.224	23,100	26,400	46,700
	70				0.53	462	35,000	0.212			
	70*				0.53	456	34,900	0.204			
	71				0.49	334	29,300	0.181			
	71*				0.44	364	32,500	0.208			
	72				0.51	402	32,300	0.212			
	72*				0.48	389	32,600	0.207			
	73				0.55	472	35,500	0.209			
	73*				0.40	417	34,400	0.198			
Average.....		39,100				34,400			21,700	23,000	41,100
II	A	2,415	43,500	0.36	0.44	477	43,500	0.246	25,000	27,700	44,500
	B	2,210	39,500	0.36	0.38	388	41,100	0.220	26,100	27,500	45,800
	F	2,460	44,300	0.39	0.50	530	43,000	0.222	28,400	27,600	50,000
	75				0.45	518	46,000	0.253			
	75*				0.44	458	42,100	0.236			
Average.....		42,400				43,100			26,500	27,600	46,800
III	50				0.36	455	50,800	0.192	37,100	34,000	46,500
	51				0.38	405	43,500	0.156	33,100	34,800	45,800
	52				0.38	493	48,800	0.202	33,100	35,600	48,600
	74				0.40	491	50,700	0.193			
	74*				0.40	488	49,400	0.193			
Average.....						48,600			34,400	34,800	47,000

TABLE 4—*Concluded*

GROUP	LOT	TEST BAR			TEST STRIP				TENSION TEST		RING
		Maximum load	Modulus of rupture	Maximum deflection	Width	Maximum load	Modulus of rupture	Maximum deflection	No. 1 strength	No. 2 strength	
IV	60				0.47	466	40,000	0.232	30,600	34,000	46,000
	76				0.40	449	43,700	0.241			
	76*				0.40	404	40,600	0.234			
	Average.....						41,400		30,600	34,000	46,000
V	2	2,085	37,500	0.34	0.48	459	39,100	0.259	23,700	23,800	43,800
	3	2,650	47,700	0.38	0.46	481	42,300	0.214	26,700	31,000	48,500
	5	2,230	40,200	0.33	0.43	422	39,400	0.223	22,700	24,500	44,800
	Average.....	41,800					40,300		24,400	26,400	45,700
VI	C	2,620	47,200	0.36	0.48	541	45,400	0.213	30,300	30,600	58,500
	D	2,200	39,600	0.33	0.46	461	40,900	0.220	25,700	27,300	50,000
	E	2,650	47,500	0.35	0.46	465	41,100	0.184	33,600	35,800	49,100
	Average.....	44,800					42,500		29,900	31,200	52,500

* Test strips cut from pipe after internal pressure test.

lot of every group except lots 70 to 76. Some difficulty was encountered in making these test specimens, many being broken in the process, but all the tests seemed trustworthy and concordant.

The tests were made in a testing machine of 10,000-pound capacity. The holding device was such as to minimize eccentricity of loading.

A summary of the results is given in table 4.

c. *Tension test specimen no. 2.* For the purpose of getting some representation of the metal at the outer and inner faces of the wall of the pipe, test specimen no. 2 was used (see fig. 7, c). The extreme length is $3\frac{1}{2}$ inches. Threaded ends were used. The middle portion was turned down to a diameter slightly less than the thickness of the wall. Three specimens were cut from one pipe that had been tested in flexure for each lot except lots 70 to 76. The specimens were more readily made than those of no. 1, and the results are concordant.

The same testing machine and a similar holding device were used as in the tests of tension specimen no. 1.

The results are given in table 4.

d. Ring. One ring 3 inches long was cut from one pipe that had been tested in flexure for each lot. The load was applied along the top element through a $\frac{1}{2}$ -inch square bar, and the support at the bottom element was a similar bar which rested on a spherical bearing block (see fig. 7, *d*). Changes in horizontal and vertical diameters were read throughout the test.

The results are given in table 4. The modulus of rupture is calculated from the formula $M = 0.159 Pd$, where M is the bending moment at the top, P the breaking load, and d the mean diameter of the pipe.

The rings broke along the top or the bottom element. The rings of group III opened up at the break generally about 0.05 inch evidently the result of internal strains. The rings of all the other lots showed no appreciable opening.

e. Test strip. In an effort to get a test specimen that would be easily made and would in any part of a section be representative of the metal throughout the thickness of the wall of the pipe, a test strip the full thickness of the pipe and $\frac{1}{2}$ inch in the other lateral dimension and 12 inches long was cut from the pipe. Generally four test strips were cut from one pipe of each lot that had been tested in flexure. For lots 70 to 76 in addition there were cut one test strip from each pipe used in the flexure test and two test strips from each pipe used in the internal pressure test.

The test strip was tested (see fig. 7, *e*) as a beam with the $\frac{1}{2}$ -inch dimension placed vertically and the load was applied equally at the one-third points of a span of 10 inches. Deflection at the middle of the span was measured throughout the test by means of a deflectometer reading to 0.001 inch.

A summary of the results of the tests is given in table 4.

GENERAL DISCUSSION OF TEST RESULTS

The average value of each strength property for each lot of pipe tested has been plotted on figure 8—bursting strength, flexural strength of pipe, tensile strength of the two forms of tension test specimens, and the modulus of rupture of the test strips and test bars. In general a correlation among the results of the tests is evident. As already stated the bursting strength of the pipe was based upon the thickness of the pipe at the break, which was also the minimum thickness. In addition, values of the bursting strength

based on the average thickness of the pipe has been placed on the diagram.

In discussing the results of the tests here reported it will be well to bear in mind that such tests may be useful (1) for giving information on the action of cast iron pipe under loads and on whether the action or behavior of the pipe differs according to the process of manufacture used, (2) for helping to determine what requirements should be inserted in specifications in order to get desired quality in the pipe, and (3) to aid in deciding how some of the inspection and acceptance tests may well be carried out.

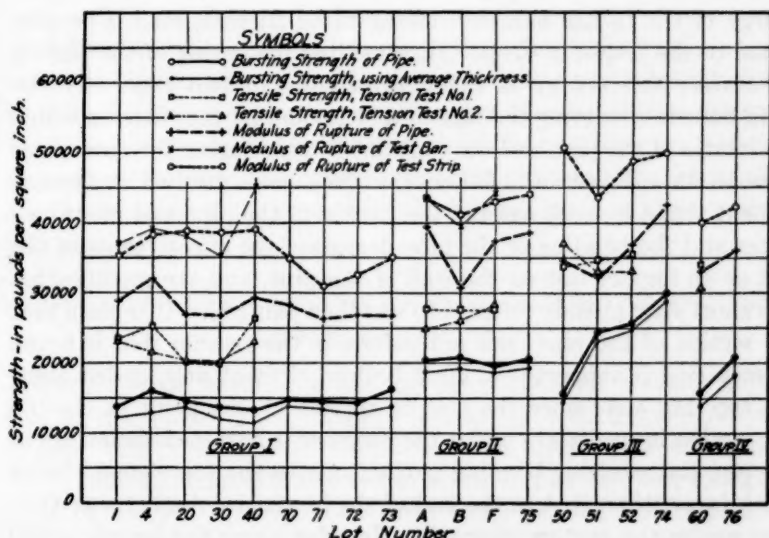


FIG. 8. PROPERTIES OF THE PIPE AND AUXILIARY TEST SPECIMENS

It will be agreed that the internal pressure test should give information of interest and value on the properties of pipe of a given lot for resisting the pressure of confined fluids. The bursting strength or resistance determined directly from the bursting pressure by the use of the wall thickness in the ordinary formula may be considered a primary property of the material in the pipe as it exists in resisting the circumferential tensile stresses in the pipe. The various other tests including tests on auxiliary test specimens need to be correlated to the bursting strength thus found if these other tests are to be useful in judging of the resistance of the pipe to internal pressure. An

effort will be made to get at such a correlation through the agency of ratios between the mechanical properties found by the various tests and the bursting strengths referred to. As to the flexure test of pipe it is evident that it not only gives information on the load that may be supported, but also supplies data on the properties of the pipe and its quality. An impact test shows resistance to falling loads and to blows received in handling and may bring out properties of the metal in the pipe. The tests of the pipe will be considered in the following order—impact test, flexure test, and internal pressure test, and then a general comparison of all the tests will be made.

In the impact test the pipe rested on supports 10 feet apart. The energy of the falling hammer, disregarding friction, etc., is proportional to the height of drop. Disregarding the spring of the testing apparatus, this energy is taken principally in two ways—by the work done in deflecting the pipe as a beam and by that in overcoming the inertia of the pipe and the contained water during the movement through this deflection. When the tests were studied it became evident that the work against the inertia of the pipe and contained water and the bending of the pipe decreased the effectiveness of the test as an impact test on the wall of the pipe, and the modification to a short span already referred to was then planned. It is plain that the section of the pipe does not deform in the manner that is found when a ring is supported along a bottom element and loaded along the top, but that since the load is applied at one point at the top the section immediately under the hammer is flattened somewhat at the top, the resulting bending moment across the top element being much larger than that at the end of the horizontal diameter or than that across the bottom element. How far along the length of the pipe the sections are thus deformed is not known; it appears that this length is dependent on the thickness of the pipe and also upon the value of the modulus of elasticity of the metal. No method of estimating the length giving effective resistance to the blow has been found, and it seems futile to attempt an analytical treatment. On figure 6 a curve for the equation $h = 16t^2$ has been drawn, h being the drop in feet and t the average thickness of the pipe in inches. It appears that the resistance to the impact of the test varies quite closely as the square of the thickness of the wall of the pipe. It is seen that there is a noticeable difference in the resistance of various lots in the impact test as shown by the position with respect to the line drawn, which represents fairly well the mean of the results.

In table 3, it is seen that the modulus of rupture obtained in the flexure tests for several lots of a group do not vary greatly from the average of the group, but that one group differs from another. It is noticeable that for a given quality of metal the thickness of the pipe has a marked effect on the load carried.

The bursting pressures found in the internal pressure tests (see table 2), except for the two pipes of lot 50 that were not included in the table, ranged for the several lots from 1500 to 3800 pounds per square inch which are ten to twenty times the sum of ordinary water pressure plus allowance for water hammer. The tensile resistance developed in the internal pressure tests (bursting strength) runs fairly uniform for group I, the averages for the several lots varying little from 14,700 pounds per square inch. Group II also gives small range in bursting strength, the average values varying little from 20,000 pounds per square inch. The lots in group III range from 15,700 to 30,000 pounds per square inch. The relatively low bursting strengths of lot 50 have not been explained; they are inconsistent with the flexure tests of the pipe and with the strengths of the auxiliary test specimens.

RELATION BETWEEN STRENGTHS OF AUXILIARY TEST SPECIMENS AND THOSE OF THE PIPES

Auxiliary test specimens are for the purpose of judging of the quality and properties of the pipe without subjecting the pipe itself to test. To be useful, the relation between the strength or stiffness of the pipe and that of the material in the form of the test specimen must be known. Before attempting a comparison and correlation of the various auxiliary test specimens with the properties of the pipe from which they were taken, it may be well to give some characteristics of the test specimens. It is usually accepted that the standard test bar may be expected to represent the quality of the metal that is poured into the mould. It may not be an index of the metal of the pipe itself. The other auxiliary test specimens possibly may be taken from a pipe rejected because of defects that are believed not to affect the quality of the metal at the places from which the test specimens are taken, or, of course, a pipe may possibly be sacrificed for providing test specimens, the remains going back to a scrap pile to be used again. The tension test specimen may determine the tensile property of the metal in the pipe in the direction of its length—whether it will also represent it in the circumferential

direction needs proof. As the properties of the metal may not be the same throughout the thickness of the wall, either by reason of differences due to chilling or to flaws that for a given process of manufacture are likely to exist in the interior of the wall or on the outside, it is desirable that the full thickness of the wall be equally represented in the test specimen. The form of tension specimen no. 1 is such that only the middle part of the thickness of wall is represented. In tension specimen no. 2 the outer portion of the wall is also represented, but not fully. In the test strip the full thickness of wall is represented and at any given distance from the neutral axis metal from every part of this thickness is equally represented. The flexure test gives modulus of rupture and not tensile strength, but a relation between the modulus of rupture of the test strip and the tensile resistance to internal pressure (bursting strength) developed in the internal pressure test may be sought for pipe made by a given process.

The test of the ring is also a flexure test. It happens, however, that the empirical formula used for calculating the modulus of rupture of the ring involves the assumption that the modulus of elasticity developed at the horizontal sections of the ring is the same throughout the thickness as that acting at the same time in the vertical sections, and the same uniformity is assumed for all sections between. This assumption markedly affects the relation between the moment developed at the horizontal and the vertical sections and hence of the actual value of the moment at either section, the sum of the two, of course, being $\frac{1}{2} Pd$. For cast iron it is evident that by reason of the varying value of this modulus of elasticity (so-called) the resisting moment developed at the vertical sections will not be 1.75 times that developed at the horizontal sections, as the use of a constant modulus of elasticity in an analysis gives, and that for different irons the relation between these two resisting moments will vary and hence the moduli of rupture calculated in the usual way will not allow accurate comparisons of the quality of the metal. For metal having a strongly curved stress-strain relation the moment developed at the sections of the vertical diameter will probably be considerably less than $0.159 Pd$. Besides, in the flexure of the ring the portions of the wall next to its surfaces receive high stress and those in the interior low stress, so that the metal is far from being equally stressed at points throughout the wall, whereas in the internal pressure test of pipe every portion of the thickness is stressed nearly equally, as is also the case in the wall at the top and bottom of the pipe in the flexure test. A

pipe having metal of high strength near the surfaces of the wall and weaker material in the interior (or having defects in the interior) would thus show different results in the ring test than would another having the conditions reversed even though the average tensile resistance were the same. Because of inherent disadvantages of the ring test, little consideration was given to it, the number of ring specimens tested being generally limited to one from each lot of pipe.

The relation between the strength properties of the auxiliary test specimens and those of the pipe when subjected to internal pressure and flexure may well be expressed by means of the ratios between these properties. These ratios have been calculated from the strengths given in tables 2, 3 and 4 and are reported in table 5. In studying the results of the auxiliary test specimens it should be kept in mind, as has already been stated, that except for the test specimens taken from lots 70 to 76 all the test strips and all the tension test pieces for a given lot of pipe were cut from one pipe. The original purpose of this was to study the usefulness of the auxiliary test specimens for determining the quality of the metal in a pipe and the uniformity obtainable in specimens cut from the same pipe. For the purpose of judging somewhat of the variation in results in different parts of a pipe a test strip was cut at four different points along the length of one pipe that had been tested in flexure for each of the lots numbered from 70 to 76. Besides, out of each of the other two or more pipes of each lot one test strip was also cut. The mean deviation of the strengths from the average of the four test strips cut from one pipe of a lot is so small, varying from 4 to 9 per cent, that it would appear that the information given in the tables is applicable to determining with a fair degree of accuracy the general relation between the results of the auxiliary test specimens and the properties found in the pipe.

It is not to be expected that the ratios for the several forms of test specimens will be the same, or that the ratios for the test by internal pressure will be the same as for the flexure test of the pipe. In making comparisons with the bursting strengths it would seem that the ratio of the strength of the test strip to the bursting strength of the pipe may be taken as 2.4 for group I, 2.1 for group II, and 1.8 for group III (disregarding lot 50). For the two tension specimens, the ratios may be given as 1.6 for group I and 1.35 for groups II and III.

The ratios in table 5 give interesting information on the relation

TABLE 5

Ratios of the strengths found in the several forms of test specimen to the bursting strength and the modulus of rupture of the pipe

For the tension test specimens the tensile resistance is used as the strength, and for the remaining ones the modulus of rupture. Strengths are given in pounds per square inch.

GROUP	LOT	BURSTING STRENGTH OF PIPE	RATIOS OF BURSTING STRENGTH					MODULUS OF RUPTURE OF PIPE	RATIOS TO MODULUS OF RUPTURE				
			Test bar	Test strip	T.T. no. 1	T.T. no. 2	Ring		Test bar	Test strip	T.T. no. 1	T.T. no. 2	Ring
I	1	13,900	2.67	2.54	1.67	1.69	2.96	29,000	1.28	1.22	0.80	0.81	1.42
	4	16,100	2.43	2.38	1.34	1.58	2.33	32,300	1.21	1.19	0.67	0.79	1.16
	20	14,700	2.60	2.30	1.38	1.37	2.85	27,000	1.41	1.25	0.75	0.74	1.55
	30	13,700	2.58	2.46	1.47	1.45	2.80	26,800	1.32	1.26	0.75	0.74	1.43
	40	13,400	3.39	2.92	1.72	1.97	3.48	29,300	1.55	1.33	0.79	0.90	1.59
	70	14,800		2.36				28,400		1.23			
	71	14,600		2.30				26,300		1.12			
	72	14,400		2.26				26,900		1.20			
	73	16,400		2.10				26,800		1.32			
Average.....			2.73	2.40	1.52	1.61	2.88		1.35	1.24	0.75	0.80	1.43
II	A	20,200	2.15	2.15	1.24	1.37	2.20	39,500	1.10	1.10	0.63	0.70	1.13
	B	20,800	1.90	1.98	1.26	1.32	2.20	30,700	1.29	1.34	0.85	0.89	1.49
	F	19,600	2.26	2.19	1.45	1.41	2.55	37,500	1.18	1.15	0.76	0.74	1.33
	75	20,600		2.04				38,600		1.19			
Average.....			2.10	2.09	1.32	1.37	2.32		1.19	1.19	0.75	0.78	1.32
III	50	15,700						34,500		1.47	1.07	0.99	1.35
	51	24,400						32,200		1.35	1.03	1.08	1.42
	52	25,800						37,000		1.32	0.89	0.96	1.31
	74	30,000						42,700		1.19			
Average, omitting 50.....				1.77	1.32	1.41	1.88						
Average, including 50.....				2.14	1.67	1.66	2.23			1.33	1.00	1.01	1.36
IV	60	15,600	2.56	1.96	2.18	2.95		33,100		1.21	0.92	1.03	1.39
	76	20,900	1.94					36,100		1.21			
Average.....				2.25	1.96	2.18	2.95			1.21	0.92	1.03	1.39

between the properties of the auxiliary test specimens and the properties of the pipe for the different processes of manufacture. The average of the ratios of the test bars to the bursting strengths is 2.73 for group I and 2.10 for group II. This may be interpreted to mean that the pipes made by the centrifugal process used for group II develop considerably higher strength in proportion to the strength of the metal poured in than do those that were made by the sand-cast process used for group I, the ratios suggesting 30 per cent increase in strength.

Similar comparisons of the tensile strength of the tension test specimens cut from the pipe with the bursting strength of the pipe are of interest. The averages of the ratios in table 5 for the two forms of tension test specimen are 1.56 for group I and 1.35 for group II and III. This means that the tensile strengths of these test specimens are 1.56 and 1.35 times the circumferential tensile resistance developed in the pipes themselves. In other words the pipes have a resistance to internal pressure of only about two-thirds of the longitudinal strength of the material in the pipe for group I, and about three-fourths for groups II and III. The discrepancies in these strengths are not traceable to defects in the pipe, for the metal in the broken pipe appeared everywhere sound and free from defects except for a few flaws in some of the sand-cast pipe. Doubtless the internal pressure test does search out the weakest places in the pipe. It is probable that internal strains in a circumferential direction contribute to the lower resistances. Whatever the cause, the fact is one that should have consideration in judging of the strength of cast iron pipe.

The ratios for the test strips given in table 5 in connection with the bursting strengths are also of interest. Naturally the modulus of rupture of the test strips calculated by the usual empirical formula is higher than the tensile strength of the material. As is well known, the difference between the modulus of rupture and the tensile strength is due to the curved form of the stress-strain curve for cast iron in the presence of high compressive strength, the tensile stress at the bottom fiber for the same bending moment being relatively smaller than would be the case for a material with a straight line stress-strain relation. The tensile strength of cast iron may be said to range from the neighborhood of two-thirds of the modulus of rupture for many cast irons to say three-fourths for those having stress-strain diagrams approaching a straight line, the exact value of the

relation also depending upon the form of the section of the test specimen and the method of applying the load. The ratios of modulus of rupture of test strip to bursting strength of pipe, given in table 5, average 2.40 for group I, 2.09 for group II, and 1.77 for group III (omitting lot 50). Using two-thirds as the ratio of modulus of rupture to tensile strength for groups I and II, which had stress-strain curves of similar form, and three-fourths as the ratio for group III, which had a less curved stress-strain diagram, ratios result which give relations between longitudinal strength of the material and the circumferential or bursting strength that are quite comparable with the relations named in the preceding paragraph. It is evident that if a ratio for the test strip be determined for a given quality of material and a given process the strengths found from the test strips may be useful in judging closely of the bursting strength of the product of the foundry, assuming that the workmanship is of good quality.

The ratios for the flexural strength of the pipe, given in table 5, permit similar comparisons, though, of course, the ratios are quite different from those for the internal pressure tests. The ratios of test bars to the modulus of rupture of the pipe show that the flexural strength of the pipes of group II is relatively higher than that of group I when the strength of the original metal is taken into consideration. The ratios of the tensile strength of the tension test pieces to the modulus of rupture of the pipe, because of the ring-shaped section of pipe-beam, may be expected to differ from comparisons made on rectangular sections. It is seen that these ratios for groups I and II are nearly the same, the modulus of rupture of the pipe thus being from one-third to one-half greater than the tensile strength of the tension test specimens, while in group III the two properties are nearly the same. It is to be noted, however, that, of course, the ratios of the test strips remain relatively the same with respect to those of the tension test specimens as before.

In two lots of pipe the ratios of the strength values show considerable variation from other lots in the same group. Lot 40 in group I gives markedly higher values for all the ratios than the others of the group. It is interesting to note that in the impact test the pipes of this lot gave the highest resistance obtained. Lot 50 in group III shows markedly higher ratios in the internal pressure test than the others in the group; this is probably connected with the low bursting strength found.

TABLE 6

Mean deviation in strengths of auxiliary test specimens from the average strength of a lot

For each type of test specimen the deviation is recorded in per cent of the average strength of the test specimens of the lot.

GROUP	LOT	TEST BAR		TEST STRIP		TENSION TEST NO. 1		TENSION TEST NO. 2	
		Number of tests	Deviation	Number of tests	Deviation	Number of tests	Deviation	Number of tests	Deviation
I	1	6	5.6	4	4.5	2	2.6	3	5.0
	4	4	7.8	4	2.4	3	6.3	3	3.0
	20	6	6.2	4	1.8	2	7.6	3	14.9
	30	6	1.6	4	2.7	1		3	3.5
	40	6	5.2	4	5.3	2	8.4	3	3.9
	70			6	3.0				
	70*			6	6.8				
	71			6	11.8				
	71*			8	7.8				
	72			6	5.3				
	72*			6	3.9				
	73			6	5.3				
	73*			6	4.8				
Average.....			5.3		5.0		6.5		6.1
II	A	6	3.2	4	2.8	3	4.3	3	0.5
	B	8	6.5	4	1.6	3	5.0	3	2.8
	F	5	9.4	4	3.4	3	2.1	3	2.5
	75			6	3.8				
	75*			12	5.8				
Average.....			6.4		3.5		3.8		1.9
III	50			4	2.9	3	1.5	3	8.3
	51			4	3.9	3	1.7	2	3.7
	52			4	8.4	3	2.3	3	1.9
	74			6	6.9				
	74*			8	6.6				
Average.....					5.7		1.8		4.6
IV	60			4	3.2	3	5.3	3	3.8
	76			8	10.2				
	76*			10	9.2				
Average.....					7.5		5.3		3.8

TABLE 6—*Concluded*

GROUP	LOT	TEST BAR		TEST STRIP		TENSION TEST NO. 1		TENSION TEST NO. 2	
		Number of tests	Deviation	Number of tests	Deviation	Number of tests	Deviation	Number of tests	Deviation
V	2	6	2.1	4	9.9	2	2.7	3	3.1
	3	6	3.8	4	2.1	2	6.0	3	5.3
	5	4	4.2	4	2.9	2	0.2	3	2.3
	Average.....		3.4		5.0		3.0		3.6
VI	C	9	4.3	4	2.1	3	4.8	3	2.7
	D	8	10.5	4	3.2	3	1.4	3	1.2
	E	7	4.6	4	1.5	3	2.5	3	1.4
	Average.....		6.5		2.3		2.9		1.8

* Test strips cut from pipe after internal pressure test.

MEAN DEVIATIONS IN STRENGTH

Information on the variations in strengths among the pipes of a given lot is given in the several tables under the heading of mean deviation. The numerical difference between the average strength of a lot and the value of each individual test piece was found and expressed in terms of the average strength. The average of these deviations for a given lot was calculated and thus represents the mean deviation from the average value of the lot. It has been expressed in per cent of the average strength. The mean deviations recorded in table 2 indicate that the pipes of the several lots as tested by internal pressure gave small variations in tensile resistance, even though there were generally only three specimens in a lot. It will be borne in mind that the tensile resistance reported is based upon the thickness of the pipe at the break; if average thickness had been used, the mean deviation might be greater. When there are three specimens in a lot the maximum deviation is, of course, one-half greater than the mean deviation. It will be noted that the average mean deviation in bursting strength for a group ranges from 4.4 per cent for group II to 15 per cent for group IV. The mean deviations for the flexure tests are given in table 3; the deviations are slightly less than for the bursting strengths. The mean deviations for the test specimens are given in table 6. With a very few exceptions the mean

deviations are small, indicating a very uniform grade of material for a given lot.

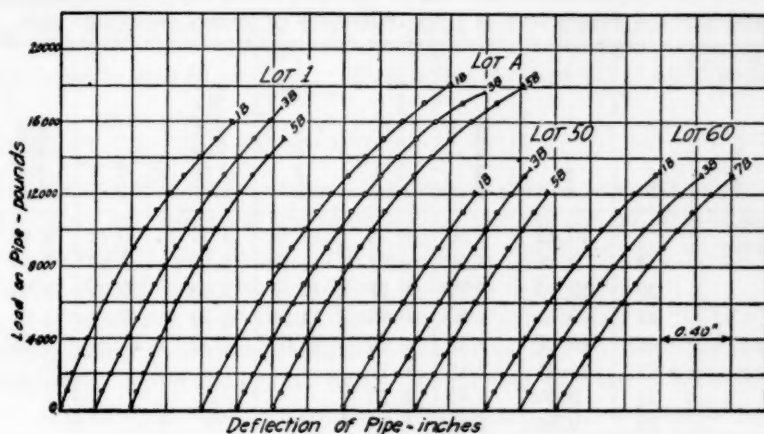


FIG. 9. LOAD-DEFLECTION CURVES FOR TESTS OF PIPE

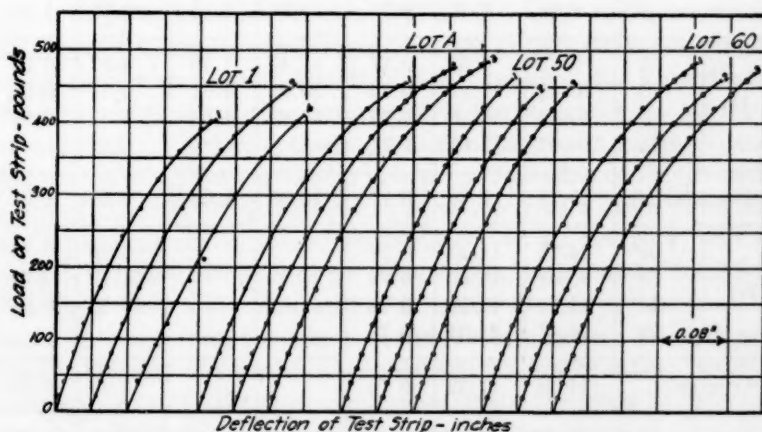


FIG. 10. LOAD-DEFLECTION CURVES FOR TEST STRIPS

LOAD DEFLECTION DIAGRAMS AND MODULI OF ELASTICITY

In figure 9 are given sample load-deflection diagrams from the flexure tests of the pipe; they are representative of the results for several groups. In figure 10 are load-deflection diagrams from the flexure tests of test strips.

In table 7 is recorded the secant modulus of elasticity calculated

TABLE 7

Secant modulus of elasticity

The value of the secant modulus of elasticity at the maximum load calculated from the flexure tests is given in millions of pounds per square inch.

GROUP	LOT	PIPE	TEST STRIP	$\frac{E \text{ OF TEST STRIP}}{E \text{ OF PIPE}}$	TEST BAR	$\frac{E \text{ OF TEST BAR}}{E \text{ OF PIPE}}$	RING	$\frac{E \text{ OF RING}}{E \text{ OF PIPE}}$
I	1	10.15	7.50	0.74	11.87	1.17	9.72	0.96
	4	9.40	7.20	0.77	11.30	1.20	8.45	0.90
	20	10.03	7.71	0.77	10.47	1.04	10.22	1.02
	30	9.13	6.63	0.73	11.10	1.21	9.23	1.01
	40	10.20	7.43	0.73	11.47	1.12	11.20	1.10
	70	10.07	7.16	0.71				
	71	9.60	6.87	0.72				
	72	9.03	6.61	0.73				
	73	10.94	7.32	0.67				
Average		9.84	7.16	0.73	11.24	1.15	9.76	1.00
II	A	9.75	7.53	0.77	11.49	1.18	9.32	0.96
	B	10.52	7.95	0.75	10.61	1.01	9.61	0.91
	F	10.42	8.25	0.79	10.85	1.04	9.81	0.94
	75	9.92	7.67	0.77				
Average		10.15	7.85	0.77	10.98	1.08	9.58	0.94
III	50	14.78	11.22	0.76			13.00	0.88
	51	15.08	11.86	0.78			11.17	0.74
	52	14.86	11.17	0.75			13.10	0.88
	74	14.67	11.05	0.75				
Average		14.85	11.32	0.76			12.42	0.83
IV	60	10.63	7.34	0.69			10.93	1.03
	76	10.26	7.56	0.74				
Average		10.45	7.45	0.72			10.93	1.03

from the data of the flexure tests of the pipe and from the auxiliary test specimens at the maximum load. For the flexure test of the pipe the formula $E = \frac{Pl^3}{48Iy}$ was used, where E is modulus of elasticity,

P the maximum load on the pipe, l the span length, y the center deflection at this load, and I the moment of inertia of the section of the pipe, which was obtained in the manner already described for the flexure test. For the test strip, with third-point loading, the formula was $E = \frac{23 Pl^3}{1296 Iy}$, for the test bar $E = \frac{Pl^3}{48 Iy}$, and for the ring $E = \frac{0.15 Pr^3}{Iy}$, r being the radius of the ring. It will be noted

that the use of these formulas in this way, of course, is empirical, but the values of E so found will allow comparisons of the stiffness of the various groups to be made. The number of specimens used in determining E is the same as that given in tables 2, 3 and 6.

It is seen from table 7 that the values of the modulus of elasticity in any group of pipe are fairly uniform for each of the forms of test specimen. From the flexure test of the pipe an average of 9,840,000 pounds per square inch was obtained in group I, with a mean deviation per lot of 5 per cent from the average, and a maximum deviation of 11.2 per cent; in group II an average of 10,150,000 pounds per square inch, with a mean deviation of 3.2 per cent and a maximum of 3.9 per cent; and in group III an average of 14,850,000 pounds per square inch with a mean deviation of 0.8 per cent and a maximum of 1.6 per cent. From the flexure test of the test strips the averages are in group I, 7,160,000 pounds per square inch, with a mean deviation per lot of 4.2 per cent and a maximum deviation of 7.7 per cent; in group II, 7,850,000 pounds per square inch, with a mean deviation of 3.2 per cent and a maximum deviation of 5.1 per cent; and in group III, 11,320,000 pounds per square inch, with a mean deviation of 2.3 per cent and a maximum deviation of 4.8 per cent. The values obtained from the test bars are more variable. As only one ring for each lot was tested, a comparison can not be made; besides, a varying relation between stress and strain for irons of different quality will affect the use of the formula for modulus of elasticity more in the ring test than in beam tests.

The averages of the values of the modulus of elasticity and the variations for different lots indicate, as was to be expected, that for any of the groups the material in the different lots has quite similar stiffness characteristics. The ratios of the modulus of elasticity obtained by test of the test strip to that by the test of the pipe have relatively little variation in the several groups (see table 7), and thus it may be accepted that the average ratio for any group can be used

for the purpose of judging of the quality of the pipe when test strips are available. The ratio, 0.75, seems to be representative of groups I, II and III. With such agreement in the results, it is evident that the data of the test strip may be taken to represent the stiffness qualities of the pipe.

The secant modulus here used disregards the curvature of the load-deflection curve. The resilience is, of course, dependent on the form of the load-deflection curve. A study of the curves indicates that an approximation to the character of the curvature may be had through the use of the secant modulus of elasticity at half the maximum load. For the flexure tests of pipe the curves examined show that the ratio of the secant modulus of elasticity for a point at half the maximum load to the value of the secant modulus at the maximum load ranged from 1.18 to 1.33 for group I, 1.22 to 1.40 for group II, and 1.10 to 1.15 for group III. For the test strips the corresponding ratios average 1.42 for group I, 1.49 for group II, and 1.30 for group III. The relative excess of the full resilience (found from the area of the load-deflection curve) over that determined from the triangular area under the secant modulus line is about two-thirds of the amount that the ratios named above exceed unity; thus, for the ratio 1.18 the full resilience will be 12 per cent greater than that derived by the use of the secant modulus line at maximum load, and for the ratio 1.33 the full resilience will be 22 per cent greater.

VARIATIONS IN THICKNESS IN THE PIPE

It is recognized that variations in thickness of wall in the different parts of a pipe will occur and that this condition must be provided for by an increase in the specified thickness beyond what would be considered necessary if the pipe were perfect geometrically. The question usually arises, what variation may be expected in good foundry practice and what limit of variation should be permitted. The matter is further complicated when a comparison of processes of manufacture needs to be considered, especially if the limits of variation may be made smaller for one process than for another. The measurement of the thickness of wall around the circumference and throughout the length for the pipes that were broken up after the internal pressure test had been applied to failure has given information on variations in thickness in pipes made by different processes and in a number of foundries that seems to have sufficient value and

interest to make some of it worth presenting here. The measured thicknesses for 27 pipes are given in figures 11 and 12. All the lots of groups I, II, and III are represented, the samples including varie-

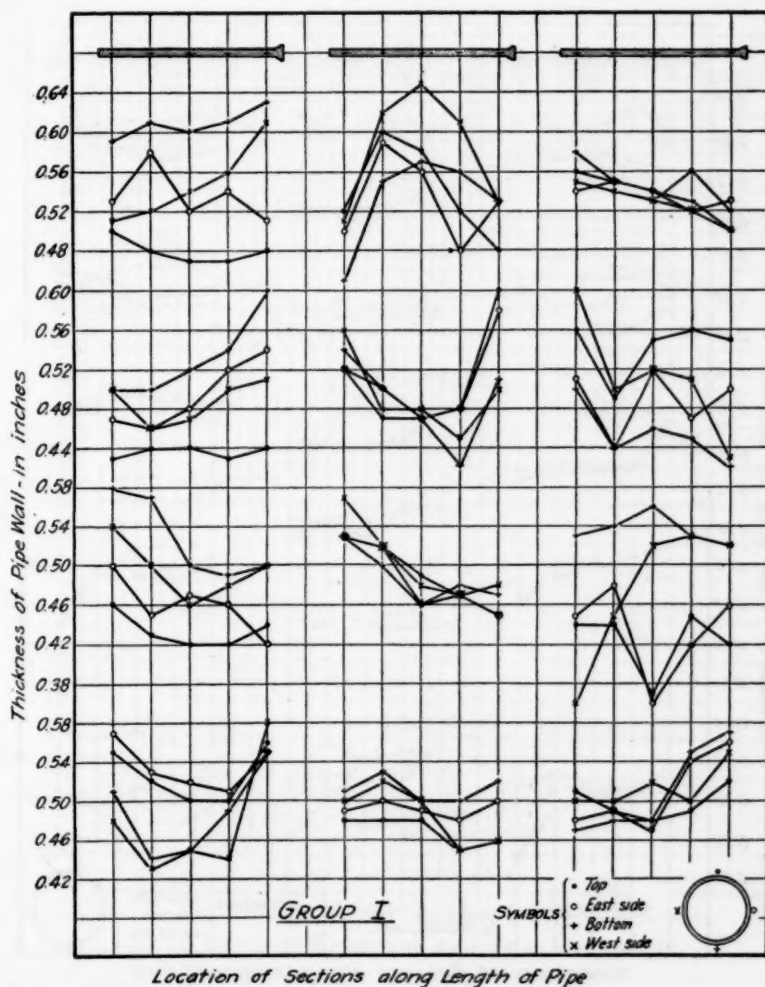


FIG. 11. THICKNESS OF PIPE AT FOUR POINTS OF FIVE SECTIONS ALONG THE LENGTH

ties of variations that will give an idea of the range in dimensions. The order on the figures is not indicative of the place of the lot in the tables. It may be said that no great difference in the variation

of thickness was found between pipes furnished by the makers and pipes from the same foundry bought in the market.

The thicknesses plotted in figures 11 and 12 are at five sections

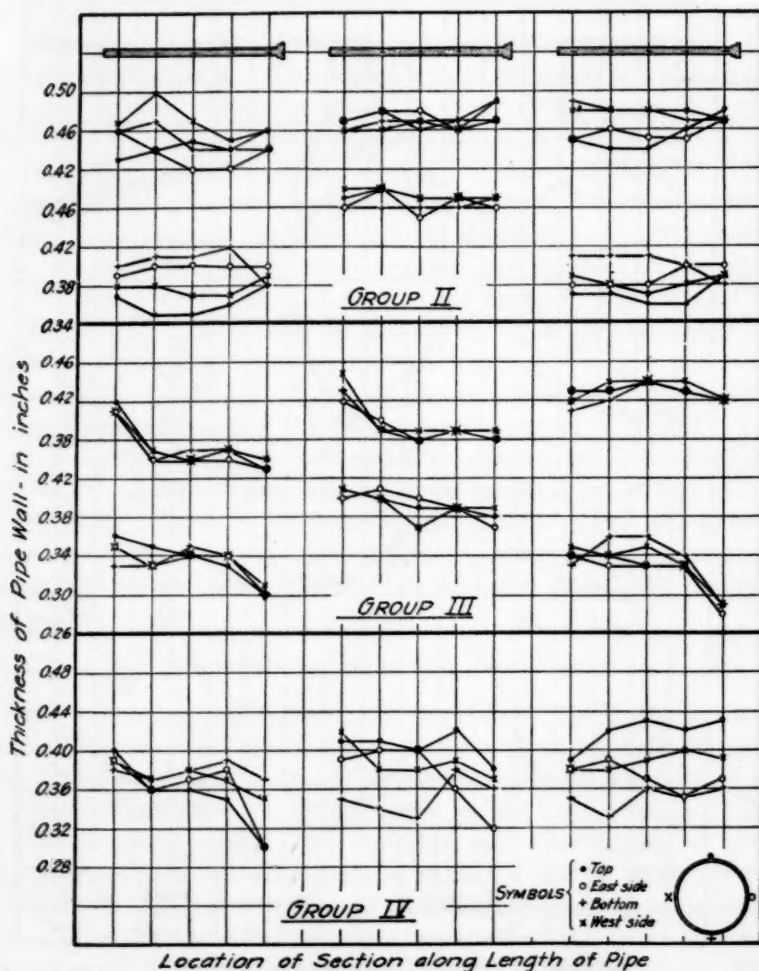


FIG. 12. THICKNESS OF PIPE AT FOUR POINTS OF FIVE SECTIONS ALONG THE LENGTH

along the length of the pipe, one near the spigot end which is plotted at the left, one near the bell end plotted at the right, one at the middle and one each at the quarter points. For each of these sections

the four points give the thickness at the top, bottom, and two sides as the pipe rested in the restraining frame in the test. In the samples shown the measurements do not bring out thin spots and thick spots which may sometimes be found in pipe.

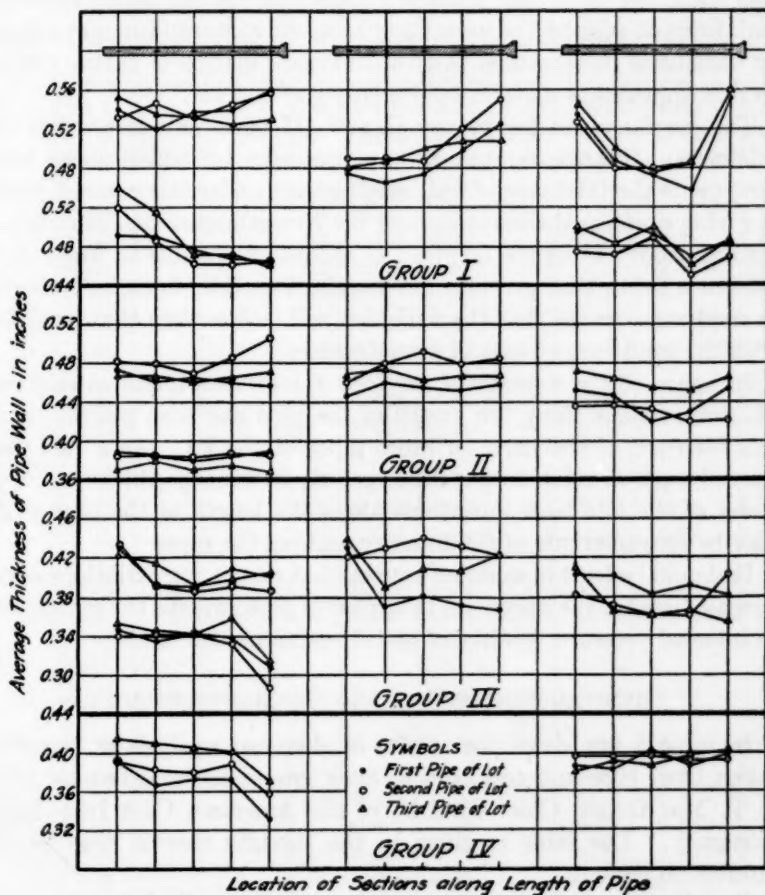


FIG. 13. AVERAGE THICKNESS OF PIPE ALONG LENGTH

The lots in group I offer a variety of variations,—eccentricity of section throughout the length; changing eccentricity from end to end for the side points and continuous eccentricity for top and bottom; thicker walls at one end or the other or both and thinner walls at the middle; and thicker walls at the middle and thinner walls at the end.

Some of the foundries have characteristic curves. The scale used for plotting thickness at the four points, of course, magnifies the variation in thickness. In very few instances did the variation reach the tolerance allowed in the A. W. W. A. specifications for cast iron pipe, 0.08 inch less than the standard thickness for the pipe, but the variations do suggest the variability in useful material brought about by variations in thickness and the increased margin of safety as the section approaches uniform concentricity of section.

The graphs given for groups II and III show less divergence in thickness. It appears that in the processes by which these lots were made the thickness of wall may be kept under fair control, both in giving uniform thickness around the circumference and in obtaining uniformity along the length. It should be possible to lower the tolerance below that given in the standard specifications, or at least to receive assurance that the variation will be less than that possible with the sand-cast process of manufacture.

In figure 13 the average of the four thicknesses found at each of the five sections along the length of the pipe has been plotted, and this for each of the three or more pipes of the lot. As a rule the several pipes of a lot do not differ greatly in average thickness, and many of the lots have variations along the length of the pipe that may be characteristic of the foundry making the pipe.

It should be kept in mind, of course, that except for variations over a small distance the minimum thickness of pipe governs the resistance to internal pressure, quality of metal remaining the same.

CHEMICAL COMPOSITION AND METAL STRUCTURE

In table 8 are given the results of chemical analysis of samples taken from pipe and test bars of each group, as furnished by Mr. J. T. MacKenzie, Chief Chemist of the American Cast Iron Pipe Company. The table is given in the thought that it may be of interest to readers.

Brinell tests made on the two surfaces of the wall of the pipe, the surfaces being ground to expose the bright metal, showed the exterior surface to be harder than the interior, though there was little difference in lots 20, 30 and 40. In the lots of group III the hardness of the exterior was found to be markedly greater than that of the interior.

Some micrographic examinations of the metal in the pipe showed considerable difference in the nature of the metal in group III from

TABLE 8

Chemical analysis of cast iron pipe and test bars
 Constituents are given in percentages by weight

GROUP	LOT	NUMBER OF PIPE	NUMBER OF TEST BARS	Si	S	Mn	P	GRAPHITIC CARBON	COMBINED CARBON	TOTAL CARBON
I	1	1		1.38	0.050	0.35	0.80	3.05	0.62	3.67
	1		6	1.37	0.055	0.34	0.80	2.96	0.70	3.66
	4	1		1.38	0.075	0.34	0.77	2.80	0.77	3.57
	4		2	1.42	0.065	0.34		2.78	0.76	3.54
	20	1		1.56	0.131	0.58	0.72	2.83	0.81	3.64
	20		3	1.54	0.085	0.42		2.87	0.72	3.59
	30	1		1.63	0.070	0.44	0.66	2.83	0.77	3.60
	30		3	1.61	0.066	0.46		2.89	0.67	3.56
	40	1		1.67	0.088	0.57	0.49	2.75	0.76	3.51
	40		3	1.64	0.072	0.42		2.74	0.75	3.49
II	A	1		1.45	0.065	0.26	0.77	2.69	0.82	3.51
	A		6	1.41	0.079	0.30		2.64	0.91	3.55
	B	1		1.47	0.061	0.32	0.74	2.80	0.76	3.56
	B		8	1.40	0.069	0.34		2.78	0.80	3.58
	F	1		1.41	0.057	0.28	0.74	2.88	0.78	3.66
	F		5	1.40	0.067	0.34		2.71	0.82	3.53
III	50	2		1.97	0.053	0.34	0.81	3.43	0.09	3.52
	51	2		1.66	0.059	0.37	0.81	3.46	0.12	3.58
	52	2		1.88	0.052	0.38	0.80	3.48	0.08	3.56
IV	60	2		1.65	0.071	0.30	0.80	2.85	0.68	3.53
V	2	1		2.09	0.050	0.52	0.84	2.95	0.58	3.53
	2		3	2.06	0.052	0.48		2.85	0.67	3.52
	3	1		1.50	0.056	0.50	0.74	2.65	0.75	3.40
	3		3	1.47	0.061	0.48		2.61	0.77	3.38
	5	1		1.37	0.063	0.33	0.80	2.75	0.75	3.50
	5		2	1.36	0.058	0.30		2.78	0.76	3.54
VI	C	1		1.44	0.060	0.40	0.71	2.52	0.79	3.31
	C		9	1.55	0.083	0.39		2.52	0.77	3.29
	D	1		2.24	0.055	0.35	0.73	2.82	0.53	3.35
	D		8	2.24	0.058	0.36		2.76	0.59	3.35
	E	1		1.42	0.070	0.36	0.71	2.52	0.85	3.37
	E		7	1.43	0.094	0.40		2.58	0.76	3.34

that in the other groups. In group III the metal was very fine grained throughout. At the exterior surface the carbon was almost wholly in combined form. Inwardly the graphitic carbon increases rapidly, soon replacing the combined carbon entirely. In the other groups the metal was fairly fine grained, that in group II being finer than that in group I. In groups I, II and IV the graphitic and combined carbon was distributed throughout the thickness of the wall.

SUMMARY

An effort will be made to bring together some of the principal results brought out by the tests:

1. The resistance to the impact test made on the 6-inch pipe supported to give a span of 10 feet varies quite closely as the square of the thickness of the wall of the pipe, though the height of drop required to cause a sensible crack was also dependent upon the quality of the metal in the pipe, as shown by variations for different lots and different groups. The bringing of the supports close together, as was done in the later modification of the impact testing machine, eliminated many of the uncertainties involved in the inertia and deflection of the pipe and thus was more distinctly an impact test, besides giving the opportunity to make tests of the pipe at its middle and ends. It is believed that an impact test similar to this modification will give useful information on the quality of pipe.

2. The modulus of rupture in the flexure test of pipe loaded at midspan gives information on the quality of the pipe which may be correlated with the results of other tests.

3. The pressures carried in the internal pressure test before failure occurred ranged from 1240 to 3950 pounds per square inch except for two pipes of one lot that failed at low loads. Failure occurred at the thinnest portion of the pipe. The pipes of group III broke up into a large number of pieces; those of the other groups failed along a crack which sometimes had branching ends and in a few cases a small piece of pipe was broken out, in three cases two such pieces. The circumferential tensile resistance of the pipe developed in the internal pressure test was about two-thirds of its longitudinal tensile strength for the lots of group I and about three-fourths for the lots of group II and III, as determined by the tests of the two forms of tension test specimens.

4. The test strip proved to be an excellent auxiliary test specimen, more easily machined and more readily tested than either of the forms of tension test specimens. The beam depth of the test strip is uniformly $\frac{1}{2}$ inch and the width covers the full thickness of the wall of the pipe and thus the fibers across the width of the beam at any distance from the neutral axis are equally stressed and equally represent all the material of the wall. The two-point loading gives high stress over a greater length than would a load at midspan and thus is more searching. The relation of the strength properties of this specimen to the bursting strength of the pipe is fairly uniform for most of the lots of pipe tested, and it is believed that the values of the ratio of modulus of rupture of test strip to bursting strength of pipe found in the tests, with suitable tolerances, will be found useful in connection with requirements for the purchase of pipe.

5. The mean deviation of individual tests from the average of a lot found in the various tests is relatively low and shows uniformity of product. It forms a useful way of making comparisons in uniformity.

6. The stiffness property of the material as indicated by the value of the modulus of elasticity of pipe and test strips, furnishes information by which the qualities of the cast iron may be judged and specified.

7. The variations in thickness of wall along the circumference and along the length found in the various lots of pipe give promise that such variations may be kept at a lower minimum and under better control in the case of the two centrifugal processes of manufacture than in the sand-cast process, and thus that a smaller tolerance may be used or more uniform margins of strength be expected in pipes made by the newer processes.

8. The lots of group II for which test bars were available gave higher resistance in proportion to the strength of the metal than did the lots of group I, thus showing a superiority in this centrifugal process. No information from test bars is available for group III, but the values of the modulus of elasticity and the character of the load-strain curves indicate that the metal was quite different from that of groups I and II, which had characteristics quite alike. The nature of the failures in the internal pressure test shows that the metal in group III was quite unlike that found in the lots of group I and II, as did also the hardness and microscopical examination. No attempt has been made to compare the suitability of the two kinds of metal as material for pipes for water-works purposes.

No attempt has been made to outline requirements for pipe of any group; nor has any effort been made to bring out what tests and inspection should be undertaken to detect variations and lack of uniformity in thickness and the presence of flaws, defects, and unsatisfactory material in pipes that have not been subjected to the tests outlined, or to avoid improper practices in manufacture.

As the tests were made only on 6-inch pipe, some of the relations found, as for example those between the longitudinal and the circumferential strengths of the metal in a pipe, may differ from those for pipe of the larger sizes.

Credit should be given to Prof. F. E. Richart, who was in immediate charge of all the tests, for his interest, skill and thoughtfulness in conduct of the tests and in working up the results. Appreciation is expressed of the cordial cooperation of the American Cast Iron Pipe Company and other manufacturers of cast iron pipe.

THE BIOLOGY OF POLLUTED WATER¹

By W. C. PURDY²

Most organisms react to their environment. Given, a suitable environment, and the organisms thrive; unsuitable, and they depart, or perhaps die out. For instance squirrels will thrive in a forest where nuts are plentiful and certain other conditions are favorable. But if the nut-bearing trees be removed, or if enemies become too numerous and effective, the squirrels will depart or will be killed off.

Given, a certain environment, a keen observer will enumerate the prevailing forms of life to be found there; or if a certain assemblage of life forms be named, the same observer will state the approximate environment in which they were found. Thus in an orchard or meadow we usually find grasshoppers, mice, certain birds, and butterflies. And if a hunter returns from his trip with game bag filled chiefly with ducks or other waterfowl we certainly know that his field of operations has been the marshes or streams rather than the hard-wood forest.

Again, if organisms respond to their environment, it follows that definite change in this environment will cause more or less disturbance in the list of occupants. Some may die, others will migrate, and still others may remain because unaffected by the particular change that has adversely affected their fellows. Squirrels may become scarce in the nut woods, but woodpeckers and flickers, unaffected by hunters, may continue to thrive as before. The advent of a sawmill on the favorite trout stream of our boyhood is followed by the migration or the death of these fish, and a few suckers and carp may subsequently constitute the chief aquatic population.

No apology is offered for this statement of elementary biological principles. It is desired that the *reasonableness* of the situation be appreciated. These general biologic principles have practically universal application. If living forms be present, in a given situation, these principles necessarily obtain.

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The application of general biological laws is not limited to life forms of large size, such as men, trees, birds, beasts, fish, etc., but the denizens of the microscopic world also are governed largely by these same principles. The availability of sufficient and suitable food means quite as much to microscopic organisms as it does to cattle; the absence of enemies in undue numbers is as vital to the continuance and well-being of an aggregation of minute, foraging rotifers as to a flock of sheep grazing on the ranch or in the foothills; absence of poisonous or inhibitory materials in the environment of the continuously-working sludge-worms means as much to them, perchance, as the protection of our coal miners from fire damp and choke damp means to these men of our subsurface industries. A sudden destruction of the usual food supply may be to microscopic organisms as great a calamity, relatively speaking, as a complete failure of crops in our own agricultural districts, and, by the same token, a continuance of suitable food supply, together with environmental conditions favoring multiplication and establishing of the species, may mean quite as much to the infusoria as does an era of prosperity and plenty to the people of the Middle West.

A Sewage-Polluted Stream. Consider a typical stream heavily polluted with sewage, with a subsequent course of 200 miles, more or less. For convenient consideration such a stream may be divided into three sections or zones:³ (1) the section of recent pollution, or that portion of stream in which the sewage is comparatively fresh, only a day or two old; (2) the zone of active decomposition, which is a direct result of the organic matter introduced as sewage, and (3) the succeeding section in which the water has to a greater or less extent freed itself from the polluting material, decomposition processes therefore are less active, and, in a word, the stream has largely recovered from its recent sewage-induced sickness. The physical characteristics of these three sections of a sewage-polluted stream are perhaps familiar to us all,—the glassy surface where the fresh sewage flows, uppermost, the gradual darkening of the water, the beginning of submerged whitish, cottonlike growths along margins or on bottom stones, and the practical absence of odor, in the zone of recent pollution; the grayish color of water due to great quantities of minute suspended matter, the distinct sewage odor, septic bubbling at times, the unsightly masses rising from the bottom sludges and

³ Stream Pollution Studies, by Suter, Moore, and W. F. Wells. Conservation Commission, State of New York, 1922. Pages 5 and 6.

floating downstream, suspended matter of all sizes, great quantities of dirty-white, furry growths attached to bottom stones or trailing from sticks, emergent weeds, or any sort of anchorage available, portions of these masses breaking off at times and floating downstream, green algae in small amounts, sometimes trailing from these same supports, a slippery, felt-like layer, sometimes greenish, often of uncertain gray-brown color, covering submerged or frequently-wetted stones or mud along margins, these are all characteristic of the second section, or the zone of active decomposition. In the final section the practical recovery of the stream is indicated by the fact that it again "looks natural," the water is no longer gray, suspended matter and gross unsightly floatage are seen only occasionally, but mats of green algae are often abundant. The whitish furry growth so common in the upper sections is not found at all, and the water has no odor. The stream seems to have quite recovered from its sewage-polluted condition.

On more detailed examination of the three differing sections of this stream we usually find well-marked differences in the prevailing kinds of plants and animals to be found in each section. It is obvious, of course, that there is no hard and fast line of demarcation, but the prevailing and characteristic forms of life in one zone are not identical with those found in the different zone or section above or below the one in question. Certain fish may be abundant in the stream at the point where sewage is introduced, feeding on the fresh organic matter but they disappear when decomposition of this organic matter depletes the water of the oxygen required by these fish and by other gill-breathers. The only fish in the succeeding septic zone, usually, are dead ones. In the lower section, fish again appear in the cleansed stream, and certain hardy and tolerant kinds sometimes venture far upstream toward the septic section but cannot go through it.

Bottom conditions in the three sections show differences also. If the current be swift, there is little depositing of suspended matter and the bottom may consist chiefly of the heavier stones, sand and pebbles. Such a stream will, in the zone of recent pollution, and for a considerable distance in the septic section below, show great quantities of whitish, furry growth carpeting the bottom stones or attached to any submerged support. This looks like fungus or mold, and sometimes it is. *Sphaerotilus*, the so-called sewage fungus, is usually found here, and various other fungi as well, such as *Leptomit* and *Achlya*. But in many cases these whitish growths are made

up largely of the colonial ciliates *Carchesium*, *Epistylis*, and *Vorticella*. These are very minute stalked animals, the animal part being shaped somewhat like a bell. In our laboratory a careful count and estimate was made of the numbers of individuals in one cubic centimeter of this furry growth. The total was over 141,000. You may estimate, if you will, the uncounted millions of these minute animals represented by the large masses of this whitish growth so common in polluted streams and at sewer outfalls. It should be mentioned, in passing, that microscopic and macroscopic fragments of these growths are continually being broken away and carried downstream by the current.

If water movement be slight, suspended matter will be deposited and resulting sludge bars and bottom muds will usually show large numbers of small reddish worms quite similar to the common earthworm except in size. These will be found in the zone of active decomposition also, and will decrease to small numbers in the final section of stream where the water has recovered from the sewage pollution.

These worms are of several varieties, as pointed out⁴ by Richardson, (4) but *Limnodrilus* is the most common. My own personal observation and study on three large polluted rivers (Potomac, Ohio, and Illinois) indicate that these worms are found in very large numbers in bottom sludges of high organic content as shown chiefly by the very repulsive odor. In sediments having little odor, further downstream for instance, these worms occur in rapidly decreasing numbers. Apparently they prefer an environment of heavy pollution. This is strikingly shown in the Ohio River, these worms being very numerous just below Pittsburg, and again coming into some prominence below Cincinnati, but are practically absent in the lower part of the river near Paducah. The situation is similar in the Potomac, these worms occurring in large numbers just below the sewer outfall, but decreasing until there is only an occasional one forty or fifty miles below. The Illinois River tells essentially the same story. From an average of 2200 per liter of mud collected near Chillicothe they decrease to 46 per liter at Havana, 57 miles below, and to 12 per liter at Kampsville, 150 miles below. (These Illinois figures are averages from about 30 mud samples from each location, collected during a period of fourteen months.)

⁴ Pages 344 to 346 of the reference cited.

These worms are interesting and possibly very important biological workmen. They burrow in various directions in the upper layers of bottom sediment, their posterior end meantime protruding a half inch, more or less, above the mud surface, and waving to and fro. They ingest the subsurface mud, and an indication of the *amount* of work done is furnished by the total quantity of fecal pellets, these being discharged at intervals of about four minutes. The total length of these pellets thus evacuated during twenty-four hours by one worm is about 69 inches, and this is approximately 45 times the length of the worm itself. There are few parallels, if any, of such *excretory efficiency extraordinary*, relatively speaking, in the known animal world.

The possible and probable importance of this worm in the economy of stream purification is three-fold, first, its *ability* to work in a nauseous environment which seems to repel most other forms of animal life. They are pioneers, so to speak, in a virgin soil. Second, the *large amount* of work done by them as a result of their great numbers and their continuous activity; and third the *kind* of work done and the net results in terms of stream purification. The *sub-surface* mud is elevated and dropped into loose piles of pellets on the surface. Each pellet has a relatively large surface area, and is subject, to a greater degree, to any agencies of purification in the surrounding water than would be the case if this particular bit of mud were still lying undisturbed an inch or so beneath the general surface. A tentative trial indicated that the mud that still remains undisturbed under the surface has a twenty-four hour oxygen demand more than twice as great as that of these fecal pellets.

Bottom conditions in the lower section of a stream, where the water has largely recovered, are quite different from the foregoing picture. The mud has little or no offensive odor, and the animal population consists largely of insect larvae of various kinds, most of which are gill breathers. The presence of these gill breathers in varied assortment, and sometimes in large numbers, would seem to demonstrate conclusively that the water now contains dissolved oxygen in amounts sufficient to sustain such life, and that the decomposable organic matter is accordingly no longer present in such amounts as to deplete the water of oxygen.

We have spoken chiefly of the larger forms of aquatic life, or of minute forms which occur in large colonies. We will now consider briefly the microscopic organisms or the plankton.

Comparatively fresh sewage contains but few active organisms as a rule, and a stream polluted with fresh sewage will at first contain mainly those plankton organisms that were common in the stream above the point of pollution. But as the sewage decomposes, using up much of the dissolved oxygen of the water meantime, there develops an assemblage of microscopic organisms that are satisfied with this particular environment. Certain of the native plankton from the stream above will continue to live, apparently indifferent, or nearly so, to the changed conditions, while other forms, for some unknown reason unable to stand the change, will die out. Still others apparently find in the presence of the decomposing sewage the ideal conditions for their development, and they accordingly multiply, sometimes to very large numbers. These latter are termed "pollutional organisms."

The term is a logical one. By common consent the addition of sewage to water "pollutes" the latter, and such organisms as thrive best in this situation may be designated by such a term as suggests their preferred environment. Those of us who live on farms add an excess of the essential constituents of sewage to a small portion of our domain and call it a "garden." The greatly enriched soil is, in a sense, a *polluted* soil, but from it we raise onions, radishes, lettuce and cabbages. From the sanitary engineer's point of view, these vegetables might be termed the "pollutional" organisms of the farm.

The microscopic pollutional organisms of water are mainly the ciliates, a few flagellates, and one or two kinds of rotifer. Just why these forms thrive so well in the decomposing sewage is not definitely known, but there is good reason to believe that many of them find their chief food in the large numbers of bacteria that are always found in such decomposing organic matter. This view has long been held by the German investigators especially, and by many others as well.

Relative to this matter a large number of experiments in our laboratory show that, when certain ciliates are present, the bacterial content of a given culture is rapidly reduced, and the ciliates meantime multiply. In a like culture which contains bacteria only (without any ciliates), the bacteria increase to a very high content and remain so for ten weeks or more. In a third culture of the same material, but which contains only ciliates which are free from bacteria (no bacteria at all being present) these ciliates all die within three or four days, being unable, apparently, to utilize the non-living suspended organic matter as a food supply. (The ciliate used in most

of these experiments was *Paramoecium*, and the culture medium was sterilized sewage.)

Returning to our polluted stream: after all, why should we be interested in the presence of great numbers of organisms in polluted water? What is the sanitary significance of these humble biological workmen?

Some of us are interested in the disposal of sewage, and a stream at once suggests one of the oldest and most convenient methods for such disposal. But others of us are equally interested in maintaining, at least to a reasonable degree, the purity of our streams, that they may be used for water supply, for recreation and fishing, and the banks utilized for residence sites. Here, then, is a conflict of interests, and a problem in relative values.

Now the organisms in polluted water ought to be a matter of interest to both these parties, for the food habits of many of these living forms will account for the safe disposal of much of the putrescible matter in the sewage. By the same token the polluted stream becomes, in time, reasonably clean, and may be used for water supply or recreation. Sewage disposal men may well consort with their brothers of the water works clan, and, presumably using the cleaner and filtered water of the lower river, together drink a toast to the long life and continued usefulness of the biological workmen, microscopic and larger, that have done much for the interests of both parties.

I once knew a farmer who had, near his house, a fine spring of excellent water. In this spring lived a trout, apparently very much at home. The small stream of water passing from the spring encountered many changes. First it passed underneath the water closet, then through a poultry yard, and through the barnyard with its usual transient population of horses, cattle and hogs. Below the barnyard the one-time spring water was accumulated to form a small fish pond, which was stocked with carp, and these carp seemed to be as much at home in the thrice-polluted water as was the trout in the spring. But these two kinds of fish could not safely change places. This being the case, each was, in a great measure, an index of the general conditions of its environment.

Many writers refer to certain aquatic organisms as "living reagents," because of the observed fact, already stated, that certain kinds apparently have a decided preference for a sewage-polluted water, or for a clean water, as the case may be. Just as *B. coli*, per-

sistently occurring in a given water, is an accepted indication of the presence of sewage contamination, so the persistent occurrence of certain plankton organisms and related forms is logically and correctly associated with the presence of the particular requirements of the organism concerned. The *occasional* presence of certain organisms, especially in small numbers, may mean little or nothing relative to the status of the water concerned; but the persistent occurrence and thriving of such organisms, and particularly if the numbers be relatively large, may logically be accepted as evidence concerning the conditions of the environment. It is merely a repetition of the trout-and-carp story.

There has been an encouraging amount of investigation of these matters in recent years, and the work is increasing. Rudolfs (1) in New Jersey, Suter and Moore (2) in New York State, the veteran biologist S. A. Forbes (3) at Urbana, Illinois, Richardson (4) at the same place, Birge and Juday (5) in Wisconsin, Needham (6) at Cornell, Kofoed (7) formerly at University of Illinois, Weston and Turner (8) at Boston, all these have made signal contributions to our more exact knowledge of the life habits and preferred environments of various forms of aquatic life, including those forms that are to be found in sewage-polluted water.

In closing let me refer briefly to the possible relation between bacteria and certain plankton forms in the Illinois River. In a study covering about 11 months the gelatine counts showed high bacterial content in the recently-polluted upper river. These counts fell rapidly as the water entered the section of active decomposition, then the decrease became more gradual. There is a rapid decline in Peoria Lake (so-called) where the water flows only about $\frac{1}{3}$ mile per hour, then a slight rise again below the city of Peoria, obviously a result of the sewage of that city being added to the river. The count then drops again as the lower section of river is reached, after 291 hours of flow, and covering a distance of 261 miles.

Meantime the total plankton (both plants and animals) shows a slight rise as water passes from the zone of recent pollution to the beginning of the septic zone, at station 263. After this the total plankton shows little change aside from a gradual increase which reaches its maximum at Havana (station 122) with very slight decrease thereafter.

While there are many plankton organisms about whose food habits we have little exact knowledge, yet we do have sufficient information

about certain ones to warrant their classification as indicators of pollution, and others as indicators of cleaner water. Applying this measuring-stick to the plankton data obtained in this Illinois investigation, we find that both the polluttional and the cleaner organisms show a rise as the water passes from the zone of recent pollution (station 286) to the section of river where septic action is more in evidence, the polluttional organisms being the more abundant. Then there begins a gradual increase in the cleaner organisms, but the polluttional forms begin to decrease, with the result that the quantitative status of these two classes is reversed, the cleaner organisms gaining and keeping the ascendancy. It is worthy of note that in passing through Peoria Lake (which is merely a mile-wide, somewhat shallow expansion of the river for about 13 miles) the cleaner organisms increase more rapidly, and also the decrease of the polluttional organisms is slightly accelerated. It is also worthy of note that the sewage of Peoria apparently causes a temporary increase in the polluttional organisms of the plankton, as was true of the bacteria.

Bearing in mind that some polluttional organisms are frequently found in water known to be relatively clean, and that certain cleaner-water organisms may persist for some time in the zone of heavy pollution, we must again give due notice that there are no hard and fast lines of demarcation relative to the plankton organisms as indicators of pollution. There is much that remains to be investigated. We know and acknowledge our limitations. But we also know and affirm the possibilities in certain plankton and related biological workmen, not only as an indication of the *presence* of pollution, but meantime as an assurance to all concerned that the proper workmen are on hand ready to dispose of this polluting organic matter, and that they will do so successfully, unless taxed beyond their capacity.

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DOUBLE CHLORINATION

By C. R. Cox¹

The increase in the degree of pollution of streams is focusing attention upon the desirable maximum loads for typical water purification plants. The magnitude of this load, if one is ever officially adopted, will determine to a large extent the relative expenditures for sewage treatment and water purification. The adoption of a moderate maximum load will imply that a high degree of sewage treatment will be needed in many cases, or that many streams will have to be abandoned as sources of water supply, whereas the adoption of a higher maximum load upon water treatment plants will permit a corresponding reduction in the degree of sewage treatment, and the economical use of polluted streams, which may be advantageously located.

The selection of a maximum filter load should be based upon the necessity of protecting the public from water borne disease, by preventing the pollution of streams to a degree which will so overload modern purification plants as to make it difficult to produce effluents of consistently good quality without elaborate supervision. The production of safe effluents requires a considerable factor of safety or reserve treatment capacity at all times to meet possible negligence, errors or unforeseen operating difficulties.

This factor of safety is usually supplied by the final chlorination of filtered waters. Sanitary engineers are generally of the opinion that the quality of the filtered water should be satisfactory without final chlorination, so that the latter would be in reality a factor of safety. Experience at many mechanical filtration plants, however, indicates that few plants treating moderately or grossly polluted waters produce a satisfactory effluent at all times without the aid of additional preliminary treatment or final chlorination. This being so, often no actual factor of safety or "overtreatment" is provided. The failure of either filtration or chlorination processes will throw therefore an undue burden upon other agencies of purification.

The obvious conclusion, therefore, is that the efficiency of filtration

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should be increased in many cases, or that more effective preliminary treatment should be provided. The design of filters has become standardized, and little improvement in their efficiency is to be expected in the near future. Chief dependence will have to be placed on improved preliminary treatment. There are several ways in which this may be done, namely, by prolonged raw water storage, double coagulation, double filtration, excess lime treatment, superchlorination and double chlorination.

PROLONGED STORAGE

Prolonged raw water storage is beneficial and has the advantage of being a natural process and free from the human element. The process is costly and thus would seldom be provided merely to improve the quality of water before treatment, except where turbid waters can be prepared for economical coagulation by short plain sedimentation, as at St. Louis and Kansas City.

DOUBLE COAGULATION

Double coagulation is being practiced at the Toronto and Portsmouth, Ohio, plants treating the Ohio river water, and is being provided at the Kansas City, Missouri, plant under construction. The process enables the operator at Portsmouth to improve coagulation, sedimentation and filtration, to reduce the amount of alum needed and to correct any errors in chemical dosing before the treated water reaches the filters. The necessity of constructing basins in most cases increases the cost of treatment plants, although an extra basin was available at Portsmouth. The increased efficiency resulting from double coagulation is obtained by modifying an important feature of all mechanical filtration plants rather than by the use of an independent process, which would function in case the coagulating process failed for one reason or other. The use of double coagulation at Portsmouth, however, enables the filters to produce a satisfactory effluent before chlorination. The efficiency of this procedure when treating relatively clear, but heavily polluted waters, is unknown. This process would prepare for efficient filtration, however, many waters difficult to coagulate.

DOUBLE FILTRATION

Double filtration prepares a heavily polluted water for final treatment without overloading the final filters. The total costs of such

plants are high and only one, at Montreal, has been constructed as a double filtration plant. The other three American examples, at Albany, Poughkeepsie and Philadelphia, and the London, England, plant, are additions to existing slow sand filtration plants. The prefilters of the Montreal plant are operated without preliminary coagulation. Nevertheless, they reduce the load on the slow sand filters and thus enable these filters to be operated at greatly increased rates of filtration. The cost of operation of this plant appears to be less than that of a mechanical filtration plant of equal capacity, although the first cost was considerably greater. The existence of the prefilters at the other three plants has made it possible to use heavily polluted streams as sources of water supply.

SUPERCHLORINATION

Superchlorination followed by dechlorination has been practiced in London. The process enables a single large chlorine dose to be used which insures adequate sterilization without the production of chlorine tastes in the treated water. It is more certain, therefore, than chlorination as ordinarily practiced, but it merely replaces ordinary chlorination. It cannot be considered as an additional treatment, but merely as a more satisfactory final treatment. As such, it has a distinct field of usefulness seldom realized. There are numerous waters which require an appreciable chlorine dose to insure satisfactory chlorination, but which will produce objectionable tastes if such high chlorine doses are applied. The effective doses are limited in these cases, therefore, to the zone between the minimum non-effective doses and the maximum, or taste producing, doses. Superchlorination followed by dechlorination, with sulphur dioxide gas or sodium thiosulphate, would permit relatively large doses without the production of tastes. In fact, the experience at London has indicated that large doses eliminate taste producing compounds more readily than moderate ones, provided the excess chlorine is destroyed by dechlorinating before the water is consumed.

EXCESS LIME TREATMENT

The excess lime treatment of water for disinfecting purposes is a possible form of preliminary treatment where chlorine in adequate doses may cause tastes, because of the presence of phenol compounds in the raw water. The treatment could be easily controlled by main-

taining a caustic alkalinity, as determined by simple hydrogen ion concentration tests. The cost of the treatment should be much less than the use of potassium permanganate or ammonium compounds, found by Sir Alexander Houston in London to be effective in the removal of tastes due to chlorophenols.

DOUBLE CHLORINATION

Double or "split" chlorination, as the name implies, consists in the application of the disinfectant at two points, namely, to the raw and to the filtered water. It is obvious that the destruction of many of the organisms in heavily polluted raw water, by preliminary chlorine treatment, will so reduce the load on the filters that they will produce a satisfactory effluent, leaving to final chlorination the function of supplying additional reserve treatment in case of temporary failure of the preliminary processes. The cost of this preliminary treatment is so much less than the other methods mentioned above that its advantages and disadvantages should be studied.

Actual results obtained at various plants demonstrate the practical value of double chlorination. Experiences at numerous plants, where chlorine is applied to raw water, will be reviewed to determine the effect of prechlorination upon coagulation and filter efficiency. Prechlorination has been practiced at Albany, N.Y.;² Avalon, Md.; Belfast, Me.; Champaign, Ill.; Cumberland, Md.; Davenport, Iowa; Elmira, N. Y.; Exeter, N. H.; Newark, N. Y.; Grand Rapids, Mich.; Harrisburg, Pa.; Louisville, Ky.; and at the following pressure mechanical filtration plants in New York State: Hyde Park, Haverstraw, Waterloo, Mamaroneck, Massena, Larchmont and Seneca Falls. Double chlorination is practiced at present at Norfolk and Newport News, Va., Toronto, Canada and Niagara Falls, Poughkeepsie, Rochester (Rochester & Lake Ontario Water Company), Rensselaer and Cohoes, N. Y.

The favorable effects of prechlorination upon coagulation were first noticed by Weston at the Exeter, N. H., plant in 1914, since which time about 0.6 p.p.m. chlorine has been added to the raw water with beneficial results. The efficiency of the filters in the removal of color, turbidity, organic matter and bacteria has been increased, and, due to improved coagulation, the alum dose has been reduced. These favorable results have been obtained also at the plant in Belfast, Me.

² Prechlorine dose added for experimental reasons during part of 1924 and 1925.

Prechlorination at Toronto, Ont., has made it possible to reduce the alum dose to the point where clarification was the chief function of the filters, and not bacterial removal. This treatment has improved coagulation, however, per unit of alum and has not injured the film of the sand grains. This film has been found by examination to be a deposit of $\text{Al}(\text{OH})_3$ and not an organic colloidal film, which would be destroyed by chlorine. Chlorophenol tastes in this water have been destroyed by superchlorination (1.25 p.p.m.) of the raw water, followed by dechlorination to remove the chlorine tastes.

Equally satisfactory results have been secured at the Norfolk and Newport News, Va., plants, where the practice of double chlorination has improved coagulation and has permitted a reduction in the alum dose.

NORFOLK, VA.

From 0.60 to 0.85 p.p.m. chlorine is added to the raw water at Norfolk, Va., so as to maintain a residual of 0.1 p.p.m. in the water as it leaves the mixing chamber. A second dose is added to the filtered water to produce a slight excess. No tastes from chlorine are noticed, provided the residual chlorine in the filtered water is kept under 0.25 p.p.m.

NEWPORT NEWS, VA.

The average prechlorine dose at Newport News, Va., is about 0.85 p.p.m. During March, 1926, however, the dose was increased temporarily to 1.50 p.p.m. A final dose of about 0.20 p.p.m. is added to the filtered water to produce a residual of 0.15 p.p.m. free chlorine. No complaints of tastes and odors have been received since double chlorination was started in August, 1923, although tastes were reported previously when the single final dose had to be much larger than at present. The prechlorination of the raw water at the Newport News plant has eliminated all scum and algae growths on the walls and gutters of the filters.

RENSSELAER, N. Y.

Data from the Rensselaer, N. Y., plant will serve to illustrate in detail the effectiveness of double-chlorination when applied to a heavily polluted water. This plant is a typical, low velocity wash, mechanical filtration plant equipped with mechanical rakes. There are 8 units, 15 feet in diameter, although only 6 units are used at one

TABLE 1
Monthly averages and maxima of the results of weekly analyses, Rensselaer, New York, 1925

MONTHS 1925	SOURCE OF SAMPLE†	COLOR p.p.m.	TUR- BIDITY p.p.m.	ALUM, GRAINS PER GALLON	CHLORINE DOSE P.P.M.		BACTERIOLOGICAL DATA					
					Raw water	Filtered water	Bacteria per cc. gelatin 20°, 48 hours	Presumptive tests for B. coli*				
								Average		Maximum		
								10 cc.	1 cc.	10 cc.	1 cc.	
January.....	Raw Basin	50	7	2.45	1.40	1.40	42,000	58,500	19/20	5/5		
	Filtered		0				46	50	4/20	1/5		
	Tap	6					19	5	2/20	0/5		
							3	3	3/20	0/5		
February.....	Raw Basin	42	32	2.56	1.05	0.83	47,400	60,000	20/20	5/5		
	Filtered		0				130	180	8/20	0/5		
	Tap	2					12	20	0/20	0/5		
							6	12	1/20	0/5		
March.....	Raw Basin	41	20	2.40	0.75	0.29	31,500	36,500	25/25	5/5		
	Filtered		0				126	120	9/25	3/5		
	Tap	3					9	12	0/25	0/5		
							4	3	1/25	0/5		
April.....	Raw Basin	41	15	2.22	0.70	0.36	25,200	27,500	25/25	5/5		
	Filtered		0				52	40	5/25	0/5		
	Tap	5					5	6	0/25	0/5		
							2	3	0/20	0/5		

DOUBLE CHLORINATION

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May.....	Raw Basin Filtered Tap	41	7	2.45	0.66	0.37	19,600	22,500		20/20	5/5
							37	40		2/20	1/5
		5	0				7	5	0/20	0/5	0/5
June.....	Raw Basin Filtered Tap	44	19	2.33	0.71	0.35	18,950	26,500		25/25	5/5
							95	250		3/25	2/5
		3	0				151†	85	7/25	2/25	1/5
July.....	Raw Basin Filtered Tap	50	5	2.60	0.95	0.48	19,440	25,000		25/25	5/5
							292	70		8/25	1/5
		6	0				192	20	3/25	2/25	1/5
August.....	Raw Basin Filtered Tap	53	6	2.80	1.20	0.69	17,875	33,000		25/25	5/5
							65	120		0/25	0/5
		8	0				13	20	2/25	0/25	0/5
September.....	Raw Basin Filtered Tap	48	15	2.80	1.20	0.59	28,200	45,000		25/25	5/5
							79	60		1/25	0/5
		6	0				14	20	1/25	0/25	0/5
						4	1		0/25	0/5	

* Number positive tubes

Number tubes inoculated

† Raw = raw water.

Basin = basin effluent—prechlorinated, coagulated and settled.

Filtered = filtered water.

Tap = tap in laboratory—after final chlorination.

‡ Single count of 520 included.

TABLE 1—Continued

MONTHS 1925	SOURCE OF SAMPLE	COLOR <i>p.p.m.</i>	TUR- BIDITY <i>p.p.m.</i>	ALUM. GRAINS PER GALLON	CHLORINE DOSE P.P.M.		BACTERIOLOGICAL DATA					
					Raw water	Filtered water	Bacteria per cc. gelatin 20°, 48 hours	Presumptive tests for <i>B. coli</i> *				
								Average				
								10 cc.	1 cc.	Maximum		
October.....	Raw	47	24	2.40	1.17	0.59	22,800	40,000	20/20	5/5		
	Basin						99	200	3/20	1/5		
	Filtered Tap	6	0				7 15	5	0/20	0/5		
November.....	Raw	45	17	2.50	0.95	0.53	18,600	20,000	20/20	5/5		
	Basin						100	50	2/20	0/5		
	Filtered Tap	4	0				9 10	3	0/20	0/5		
December.....	Raw	48	12	2.72	0.90	0.54	18,700	23,000	25/25	5/5		
	Basin						94	50	5/25	1/5		
	Filtered Tap	7	0				16 15	4	1/25	0/5		
Maximum raw water count of year.....	Raw	42	50			Feb. 24	60,000		5/5			
	Basin						180		1/5			
	Filtered Tap	0	0				20 12		0/5			
Minimum raw water count of year.....	Raw	50	5			Aug. 19	11,750		5/5			
	Basin						50		0/5			
	Filtered Tap	8	0				6 2		2/5			

time. The raw water pumps operate at the rate of 3.5 m.g.d. which produces an average filter rate of 146 m.g.d., with 6 units in use.

The raw water is pumped from the heavily polluted Hudson river just above the cities of Rensselaer and Albany, and is dosed with chlorine and alum just before reaching the low lift pump, where some mixing is provided. The treated water is then allowed to coagulate and settle in four cylindrical basins, 16 feet in diameter and 20 feet deep, which provide a short detention period of one hour. The filtered water is chlorinated again as it is pumped to the distribution system.

Table 1 gives the monthly averages of the chemical doses and the results of weekly bacteriological examination of the raw, the pre-chlorinated and settled, the filtered waters, and the filtered water after final chlorination. The results of the examination of weekly samples, having the highest bacterial content in the raw water for each month, are also given to indicate the maximum observed bacterial load on the plant.

The raw water is highly colored and of moderate turbidity. The 20 degree gelatin count of the raw water is very high and is an approximate measure of the heavily polluted nature of the Hudson river water at this point. The presumptive tests for *B. coli* were not made in a sufficient number of dilutions to enable the *B. coli* content of the samples of water to be calculated. More complete bacteriological examination of the raw Hudson river water at the Albany filtration plant indicates that the *B. coli* index varies between 100 and more than 100,000 per 100 cc. of water, depending upon the stream flow and the prevailing degree of pollution.

Analyses of samples of raw Hudson river water collected near the Rensselaer intake indicate that the organic matter from sewage and industrial wastes is present in sufficient quantities to produce oxygen consumed values varying between 7 and 25 p.p.m. A large quantity of paper and pulp mill wastes is discharged into the Upper Hudson river and is responsible for most of the color of the river water and also for a considerable part of the high oxygen consumed values. This large quantity of organic matter in the water and the high degree of bacteriological pollution places a heavy burden on the purification process. It is interesting to observe, therefore, that the inexpensive Rensselaer filtration plant is able to treat this water satisfactorily, as evidenced by the fact that no deaths from typhoid fever have occurred in the city since 1922.

The alum dose is fairly constant and moderate, considering the degree of pollution of the water. This dose is adjusted by the operator to produce clear effluents. It is impossible to ascertain what the bacteriological removal of the coagulation basins would be if the raw water were not chlorinated. It is also impossible to learn from the available laboratory data what saving of alum resulted from the preliminary treatment of the raw water with chlorine, because the raw Hudson river water was of a less polluted nature, requiring a different alum treatment, before 1917 when prechlorination was adopted. James M. Caird, consulting chemist of the Rensselaer Water Company, states, however, that he is of the opinion that prechlorination is an aid to coagulation. The sand beds are maintained free from mud balls and organic growths by the preliminary treatment and the washing procedure.

In general, two-thirds of the total chlorine dose is applied to the raw and one-third to the filtered water. In this way the chlorine treatment is "split" so that the largest dose is added to the raw water where the rate of chlorine absorption is greatest and where the effect of over-dosing would not be noticeable in the water delivered to the consumer. The actual practical method of controlling the doses is as follows. The raw water chlorine dose is increased to a point where the water delivered to the filters is not heavily polluted with bacteria. The final chlorine dose is then adjusted to produce an excess chlorine dose of about 0.2 p.p.m. in the laboratory tap. If the concentration of free chlorine is found upon frequent examination to be less than the desired, minor corrections are made by increasing the final chlorine dose. If the amount of free chlorine, however, in the sample from the laboratory tap is much less than desirable, the dose applied to the raw water is increased and minor modifications are subsequently made in the final treatment. No attempt is made to maintain a constant quantity of free chlorine in the unfiltered water.

No taste producing compounds have developed from the reaction of the raw water and the chlorine, except those noticed occasionally during the last six months, which are phenol-like in nature and probably due to gas plant wastes above the intake. It may be that other taste-producing compounds are produced occasionally and are removed by the filters, although there are no data upon this subject. It should be emphasized, however, that no disagreeable *chlorine* tastes and odors have been produced in the water delivered to the consumers in Rensselaer except at infrequent intervals when the final

chlorine dose was larger than desirable. These are true chlorine tastes produced by excess chlorine in the tap water which are comparable in every way with similar excesses resulting from temporary overdosing by single chlorination plants. This is especially true when the dose of chlorine is very high during times of minimum flow in winter and when ice prevents reaeration, as in January, 1925.

The taste of chlorine in the tap water would have been much less at this time had a greater portion of the total dose been applied to the raw water. This was not possible, as the capacity of the raw water chlorination apparatus was not sufficient for the purpose. It may be concluded, however, that the Rensselaer plant is capable of producing a tap water with a very low bacterial content and with no, or only a slight chlorine taste, except when the raw water pollution is excessive and taste producing doses of chlorine are necessary. Aeration to remove certain compounds having great chlorine absorbing capacity, followed by prechlorination and coagulation in a larger basin, would lower the required doses, as well as permit the use of much larger prechlorine doses, and correspondingly smaller final doses, due to the increased detention period of the larger basin available for the prechlorination reaction.

POUGHKEEPSIE, N. Y.

The prechlorination of the raw water at Poughkeepsie, N. Y., has greatly reduced the load on the prefilters. The filtration plant consists of a coagulation basin with an 18-hour detention period, typical rapid mechanical filters, aerator, slow sand filtration plant and final chlorination. Since the raw water has been chlorinated, the effluent from the preliminary mechanical filters is of a satisfactory quality at most times so that the final filters provide excess treatment capacity in addition to that provided by the final chlorine dose. In this way, Poughkeepsie has in reality two factors of safety to guard against the passage of bacteria through the treatment plant.

Double chlorination at Poughkeepsie produced the typical results shown in table 2, in September, 1924, with an alum dose of $1\frac{1}{2}$ g.p.g., a preliminary chlorine dose of 0.48 p.p.m. and a final chlorine dose of 0.25 p.p.m. applied to the effluent of the slow sand filters.

The agar count was reduced, in 1924, from an average of 3264 to an average of 70 by the preliminary treatment consisting of chlorination, coagulation and sedimentation. None of the 265 tests for *B. coli* in 10 cc. portions of the final effluent was positive during this year.

ROCHESTER, N. Y.

From two-thirds to four-fifths of the total chlorine dose is applied to the raw water of the Rochester and Lake Ontario Water Company's plant at Rochester, N. Y. Raw Lake Ontario water at this plant has an average count of about 4000 bacteria per cubic centimeter, with maximum counts over 60,000 and minimum counts under 100. This water is typical of Great Lakes waters in general in being susceptible to chlorination with small doses. The chlorine doses are

TABLE 2
Results of double chlorination at Poughkeepsie, New York

	RAW WATER	SETTLED WATER	PREFILTER EFFLUENT	FINAL FILTER EFFLUENT	TAP WATER AFTER FINAL CHLORI- NATION
Turbidity, p.p.m.....	20		Trace		0
Color, p.p.m.....	18		5		3
Bact. per cubic { 37°C. agar....	11,000	3400	2200	60	1
centimeter... { 20°C. gelatin..	13,500	8200	7400	55	2
B. coli per 100 cc.....	10,000+	4	4	0	0

TABLE 3
*Average of daily results for February, 1926, Rochester and Lake Ontario
Water Company*

STATION	BACTERIA PER CUBIC CENTIMETER 37°C. AGAR	PER CENT POSITIVE PRESUMPTIVE TESTS IN 1 CC.
Raw.....	4475	90
Prechlorinated, coagulated and settled.....	13	8
Filtered after secondary chlorination.....	3	0

varied with the changes in the temperature of the water, smaller doses being used when lower temperatures obtain. Table 3 indicates how an average preliminary dose of chlorine of only 0.14 p.p.m. was sufficient to reduce greatly the load on the filters during February, 1926. A very small final dose of chlorine of 0.035 p.p.m. supplied reserve treatment during the month. The average alum dose was 0.77 g.p.g.

NIAGARA, N. Y.

Table 4 shows interesting average results obtained at the Niagara Falls, N. Y. plant of the Western New York Water Company during 1924.

The supply is derived from the comparatively clear but polluted Niagara river, the water from which cannot be heavily chlorinated without the production of tastes. The moderate preliminary chlorine dose of between 0.2 p.p.m. and 0.3 p.p.m. effectively reduced the bacterial load on the filters. The small chlorine dose of between 0.10 p.p.m. and 0.15 p.p.m. easily produced a satisfactory final effluent. The disinfecting action of the prechlorine dose is not as marked as in the case of the heavier dose at the Rensselaer plant, even though the organic content of the raw Niagara river water is much less than that of the Hudson river water. This would substantiate the view expressed below that a large dose of chlorine, present for relatively

TABLE 4
Results of double chlorination at Niagara Falls, New York

STATION	BACTERIA PER CUBIC CENTIMETER 20°C. GELATIN	PER CENT POSITIVE PRESUMPTIVE TESTS IN 1 CC.
Raw.....	17,926	99.82
Settled prechlorinated.....	5123	90.16
Filtered.....	1172	54.92
Water after final chlorination.....	8	0.11

short periods, is more effective than smaller doses applied to waters, where the rate of reduction in the concentration of free chlorine may be relatively slow. These results also may indicate that chloramine compounds may be formed when chlorine is added to heavily polluted water, such as at Rensselaer, which would be relatively more effective as disinfectant than chlorine itself.

ALBANY, N. Y.

The application of from 0.7 to 1.3 p.p.m. chlorine to the raw water at the Albany plant during part of 1924 and 1925 resulted in a marked decrease in the bacterial load on the prefilters, without any harmful effects upon these filters. No marked improvement in coagulation

was observed during the period when prechlorination was practiced, although such an effect was not specifically studied during the experiments.

CHAMPAIGN AND FRANKFORT, ILL.

Growths of *Crenothrix* in the sand beds and underdrains were destroyed by prechlorination at the Champaign and Frankfort, Ill., plants, with a resulting increase in the efficiency of these iron removal plants.

DAVENPORT, IOWA

Algae growths were suppressed at Davenport, Iowa without any ill effects upon coagulation. No tastes in the treated water have been produced at this latter plant. In fact, positive tests for chlorine in the filtered water are avoided by the operator.

ELMIRA, N. Y.

The application of an average of 1.1 p.p.m. chlorine to the raw water at Elmira, N. Y., has not reduced the efficiency of the filters for the removal of suspended solids, and no tastes have been recorded due to this high chlorine dose, indicating an efficient dechlorination ability of the filter beds, and freedom from tastes which probably would have been produced had relatively large doses of chlorine been applied to the effluent, instead of to the influent.

COHOES, N. Y.

The same experience is met with at the Cohoes, N. Y., plant, where the filters remove an excess of 0.25 to 0.30 p.p.m. free chlorine from the water applied to them without any apparent effect upon the coagulum on the sand beds.

PRESSURE FILTERS

The prechlorination of the water at the seven pressure mechanical plants in New York State, mentioned hitherto, has been practiced because the effluents of these plants are under pressure and thus not readily chlorinated. No harmful effect of the chlorine dose on the filters has been reported, although the doses are in general higher than would be the case were final chlorination practiced.

OTHER CITIES

Experience at the Cumberland, Md., and Grand Rapids, Mich., plants indicates that prechlorination is a slight aid to coagulation, without being detrimental to filter efficiency. Tastes are produced in the filtered water only when the dose of chlorine is in excess of that needed in practice.

Notwithstanding these favorable results, experimental prechlorination led to the destruction of the film on the sand grains at the Cleveland plant and to a marked reduction in the filter efficiency. Unfavorable results were obtained, also, at the Louisville plant, where the application of chlorine to the filter influent for six years did not prove as reliable and effective as when applied to the filter effluent during the last four years. These latter unfavorable results may not have been secured had the dose of chlorine been applied to the raw water entering the coagulation basin, so as to provide an adequate detention period, rather than to the filter influent. The application of 0.6 p.p.m. chlorine to the raw water at this point was not effective against algae.

CONCLUSIONS

Most of the above data indicate certain advantages for double chlorination over other methods of preliminary treatment of water. These advantages may be summarized briefly as follows:

a. Preparation of heavily polluted raw waters for filtration, so that the filter effluents will be of satisfactory sanitary quality before the final dose of chlorine is added.

b. The use of two independent chlorination plants at all times naturally enables greater confidence to be placed in the disinfecting process, because it is unlikely that both plants will fail to operate at the same time, especially if the plants are housed in separate buildings. Both plants can be so connected that each will chlorinate either the raw water or filtered water, so that the failure of one plant will result in nothing more serious than the temporary chlorination of only the raw or filtered water until the other plant is repaired. The holding of a third chlorination plant in reserve naturally will obviate the necessity of any interruptions in double chlorination.

c. Experience has shown that the exposure of bacteria to high concentrations of chlorine for relatively short intervals of time is more effective than exposure to lower concentrations for longer

periods. The chlorine absorbing capacity of the average polluted raw water is sufficient to permit the addition of relatively large doses to the water entering coagulation basins without much, if any, free chlorine being present in the settled water applied to the filters. Such treatment subjects the organisms in the raw water to an active chlorine dose for much longer periods than obtains in the case of the usual dose applied to filter effluents, where long periods of contact cannot be used in many cases without having free chlorine in the tap water. The disinfecting action of the large prechlorine dose is more marked, therefore, even though most of the chlorine reacts very rapidly with the organic matter in the raw water.

d. The long reacting period in coagulation basins and the chlorine absorbing capacity of the filter beds at most plants permit relatively large overdoses of chlorine before free chlorine appears in the filter effluents. This is of practical value, in that it permits operators to overtreat raw waters at times of excessive pollution. In fact, the dechlorinating capacity of the filters makes the preliminary chlorination of the raw water comparable to superchlorination.

e. Prechlorination of water containing large quantities of organic matter may result in the formation of chloramine compounds which will persist in the filter beds and thus provide disinfecting action during temporary cessation in the application of chlorine.

f. Prechlorination aids coagulation. This action may be due to the effect of the chlorine dose upon the organic matter in the raw water, so that the physical state of the stabilizing "protective organic colloids" is altered, or that the organic matter is "aged" by the chlorine, through the formation of saturated compounds.

g. One of the advantages of prechlorination is the resulting oxidation of iron, the precipitation of sulphur compounds, and alteration of taste-producing essential oils due to algae, through the formation of substitution products having no taste or odor. There may not be many plants where this factor is of major importance, but the existence of such a treatment agent under the control of operators would be a valuable adjunct to many filtration plants. In fact prechlorination of water applied to mechanical filters would enable final effluents to be produced which would be similar in quality to those of slow sand filters, where biological oxidation greatly changes the character of the dissolved organic matter.

h. Prechlorination serves the useful purpose of preventing the growth of algae and slime in coagulation basins and filters, although

chlorine is not as effective as copper sulphate in the destruction of existing growths of vegetation.

It may be objected that the removal of most of the bacterial load from the filters will permit operators to neglect these units and to rely more and more upon chlorination to remove bacteria. This tendency should not be countenanced any more than in the case of typical filtration plants, where final chlorination alone does not supply sufficient reserve treatment capacity to justify reliance only upon chlorination.

Another criticism of double chlorination is that the addition of large quantities of chlorine to raw waters may produce reaction products, other than trichlorophenols, which are noticeable to the taste and which are not removed by the filters. No definite conclusions can be reached regarding this subject, due to lack of data. Available evidence, however, indicates that no such taste producing reaction products are present in the effluents of the plants mentioned above.

It may be concluded, therefore, that double chlorination is less costly than other methods of preliminary treatment and it can be practiced at most mechanical filtration plants without the necessity of making major structural changes. The doses of chlorine may be easily controlled by the excess chlorine test. The treatment thus provides filter operators with a flexible and economical means of reducing and equalizing bacterial load on filters treating heavily polluted water, improving coagulation, oxidizing iron, precipitating sulphur compounds, altering taste producing substances and preventing organic growths from developing in coagulation basins and filters. The selection of maximum filter loads, therefore, should be made with due consideration to the possibilities of utilizing this method of treatment for many heavily polluted waters.

Acknowledgement is here made to the many chemists and engineers for their kindness in furnishing the data discussed in this paper.

THE PROBLEM OF STEAM BOILER CORROSION¹

BY FRANK N. SPELLER²

Before considering ways and means for preventing corrosion in boilers, it is desirable to take an inventory of the more important facts which have been well established, with reference to the mechanism of corrosion in general.

The following seem to be the more important facts known at present regarding the corrosion of iron.³

1. It is well known that iron will not corrode at normal temperatures in the entire absence of moisture.

2. The presence of oxygen is also essential if appreciable corrosion is to take place in ordinary water. Oxygen and water alone will cause corrosion even in the absence of carbon dioxide or other acids. In natural water, corrosion is almost directly proportional to oxygen concentration, if other factors do not change. Oxygen also accelerates the corrosion of iron in dilute acid solutions.

3. Corrosion in acid is much more rapid than in neutral solutions, and the latter is more rapid than corrosion in alkaline solutions.

4. Hydrogen gas is usually evolved from the surface of the metal during corrosion in acid solutions, but the evolution is very much less in neutral and alkaline solutions.

5. The products of corrosion include, mainly, black or green ferrous rust which forms next to the metal, and reddish-brown ferric rust which forms the outer layer, where sufficient free oxygen is present, with graded mixtures of the two in between. When iron corrodes in the atmosphere the amount of ferrous rust is small, but when formed under water, the ferrous rust often amounts to more than one-third of the corrosion products.

¹ Presented before the Buffalo Convention, June 9, 1926.

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³ This and some other of the contents of this article are taken from a book by the author and his collaborators entitled "Corrosion—Causes and Prevention" (McGraw-Hill Book Company, Inc., 1926), which contains further details on this subject.

6. In corrosion in natural water the precipitated rust usually carries down some calcium, magnesium, and siliceous compounds, together with other insoluble material from the water. These substances have considerable influence on the structure and density of the rust coating on the metal surface.⁴ If the rust coating is loose and non-adherent, under ordinary conditions the rate of corrosion may be accelerated locally but, on the other hand, if it is uniformly dense and adherent, it may cut down the rate of corrosion very considerably.

7. In most cases, the initial rate of corrosion is much greater than the rate after a short period of time. This is particularly noticeable in alkaline solutions. As an exception, however, it should be noted that the initial rate of corrosion of a highly polished metal surface is abnormally low.

8. The corrosion rate increases with the concentration of certain neutral salts to a certain point and then decreases to a minimum at normal temperature, other things being equal. (At elevated temperatures, however, the rate does not seem to decrease with the concentration.) Dissolved salts often increase the tendency to pitting especially when they form protective coatings which are not continuous.

9. In natural waters the rate of corrosion generally tends to increase with increase in the velocity of motion of the water over the metal surface.

10. Composition of the iron, within the ordinary variations found commercially, has little or no effect on corrosion underwater, but sometimes it has a marked effect in atmospheric and acid corrosion. From the standpoint of corrosion, homogeneity of a metal is not usually so important as external conditions.

11. The condition of the metal surface in submerged corrosion may not affect the *total* corrosion, although it may have a marked tendency to *localize* the action and form pit holes.

12. Corrosion of iron is rarely uniform over the entire surface. Dissimilar metals in contact with each other, or with electrically-conducting material in solution, tend to accelerate corrosion locally. This action is indicated by an electric current which flows through

⁴ The term "coating" is used to designate a more or less continuous layer of solid matter on the surface of a metal. The term "film" is used to indicate a very thin coating consisting of either a liquid or a solid.

the solution from the more corrodible to the less corrodible material, i.e., from the anode to the cathode.⁵

13. Variation in concentration or in composition of solutions in contact with a metal tends to localize corrosion at certain areas of the surface (i.e., accelerate it) and retard the action at others. When a portion of the metal in solution is protected from diffusion of oxygen, it becomes anodic to other areas which are in contact with a solution richer in oxygen, i.e., corrosion is more active at such protected areas. The smaller the anodic areas with relation to the associated cathodic areas, the greater is the rate of corrosion at the anodic points and the greater the tendency for the formation of small holes or pits.

14. The solution under the porous cap of rust over active pits tends to become more concentrated in soluble salts. When a pit has gotten well started it seems to deepen at an increasing rate.

15. The polarity of a certain area is often reversed during the progress of natural corrosion, in which case, of course, pitting is not so pronounced.

In attempting to explain and correlate these facts which have been established by observation and experiment, the electrochemical theory has been developed. The name is derived from the fact that corrosion and many other chemical reactions usually produce an electric current which, however, is often very small. This is not to be confused with stray current electrolysis due to electric currents external to the metal, although the damage done to the metal by the latter and the rust produced often have much the same appearance as in ordinary corrosion.

Before discussing boiler corrosion it may be well to picture the mechanism by which these reactions occur.

⁵ A cathode is the pole of an electrolytic cell where current leaves the solution and enters the metal; an anode is the pole where current leaves the metal and enters solution. Anodes are sometimes spoken of as anodic areas or surfaces, and cathodes as cathodic areas. Anodic and cathodic areas may exist on a single piece of metal. The terms anodic and cathodic are often used in such a sense as: iron is anodic to copper. This means that if pieces of iron and copper in electrical contact are immersed in a solution of an electrolyte, the iron will act as anode and go into solution more rapidly, while the copper will act as cathode and will be less liable to enter solution. The terms "anodic" and "cathodic" are here employed instead of the terms "electropositive" and "electronegative," which are not always used in the same sense. In cases of corrosion of ferrous metals, iron is dissolved at the anode and hydrogen plated out at the cathode.

Iron, like all other materials, has a definite, inherent tendency to go into solution in water. The metal, however, can enter solution only by displacing some other element already in solution. For instance, a piece of iron placed in copper sulphate goes into solution, but at the same time copper is plated out and appears on the surface of the iron. In the ordinary case of iron immersed in water, hydrogen is the element plated out, and this element gathers on the surface of the iron in the form of a thin invisible film.

The presence of this film tends to obstruct or congest the progress of the reaction by insulating the metal from the solution. This interference may become so effective in natural waters as to stop corrosion altogether. Thus, the *first* stage of corrosion comes to a stop so quickly that no appreciable damage is done to the metal if the process goes no further.

In order that corrosion may proceed, the film of hydrogen must be removed. This can happen in two ways: either it may combine with oxygen in solution to form water, or it may escape as gaseous hydrogen.

Dissolved oxygen is usually present in water solutions, and removes the hydrogen film by reacting with it to form water. The process is then free to continue, that is to say, more iron can go into solution, more hydrogen can plate out, and the process can continue at a rate determined by the speed with which the oxygen removes the hydrogen. This is the *second* stage of corrosion and accounts for the continuance of the process in the great majority of cases.

In acids, the same reaction takes place. In addition to this, however, the tendency for hydrogen to plate out is much greater, and so much of it gathers on the metal surface that it is forced off in the form of hydrogen gas bubbles. Corrosion, therefore, is proportionately more rapid in acid solutions than in natural waters.

Ordinarily, the iron which goes into solution is thrown down as rust. After a time the rust, together with insoluble material from the water, may form a protective coating on the surface of the metal which interferes with the corrosion reactions by insulating the metal from the solution.

IMPORTANT FACTORS IN STEAM BOILER CORROSION

From the foregoing consideration of the mechanism of corrosion in general, it seems that corrosion in boilers is caused by two groups

of contending forces. The first is the tendency of the metal to go into solution and is represented by its solution pressure. The initial corrosion thus started is maintained by the depolarizing effect of free oxygen and by the acidity (hydrogen-ion concentration) of the boiler water. The second group is made up of the protective or restraining influence of such factors as protective coatings deposited on the metal from the water, the polarizing effect of hydrogen in the absence of oxygen, the over-voltage of the metal to the discharge of hydrogen gas, alkalinity of the boiler water (low hydrogen-ion concentration), and the protective effect caused by contact with a more anodic metal (such as zinc), or through an externally applied counter-electromotive force. The corrosion products directly in contact with the metal on the evaporating surface of steam boilers have been found to consist mainly of the black magnetic oxide of iron (Fe_3O_4), with a larger proportion of the lower ferrous oxide when the oxygen is very low. The resultant of these and other influences determines the rate of corrosion under a certain set of conditions and, of course, the rate will usually vary if any of the essential factors are changed.

The most serious form of corrosion is when the action is concentrated on relatively small areas, resulting in pit holes. This is due to certain electrochemical reactions referred to above, by the action of which certain areas remain anodic to the rest of the surface. In this way the metal may be perforated before more than 5 or 10 per cent has been removed by rusting. The mechanism of pitting in boilers requires further investigation, but enough is known at present to make it practicable to minimize this trouble. The degree of prevention which may be economically applied, depends largely upon the cost of replacing corroded parts and the inconvenience and loss entailed by interruption or inefficiency in service.

FEED WATER IN GENERAL

All of the materials which constitute the earth's crust are more or less soluble in water. Their solubility is often greatly increased by the presence of carbon dioxide or alkalis in the soil water. Consequently, most natural waters are impure. Many of these are entirely unfit for boiler use without proper treatment. In some cases, a satisfactory water cannot be produced by treatment, and there is no other resource but to use distilled water or to find a more suitable

supply. The use of poor quality water in high-pressure boilers leads to far-reaching difficulties when the water carries an undue amount of scale-forming or corrosive matter, and may result in the formation of heavy scale on tubes and plates and in corrosion of the boiler metal and equipment, sometimes accompanied by embrittlement of the metal. Operation under such conditions may result in tube failures (due to overheating or pitting), leakage, loss of heat, intermittent and unreliable operation of the plant, and large operating expense. Evidently the use of a good quality of water will greatly improve many of these items and, as a matter of experience, has usually proved to be a paying investment.

In a few localities, natural water is sufficiently pure to be used without treatment to remove incrustants, but no water should be used without treatment for the prevention of corrosion, although this may involve only the removal of a large portion of the dissolved gases. The higher the pressure, the more necessary it is that the water be as free from injurious impurities as possible. On the other hand, while heavy incrustants are undesirable from the standpoint of heat efficiency, the presence of a light deposit often affords considerable protection against corrosion. In the absence of any deposit, therefore, it becomes necessary to take all possible precautions against corrosion. For instance, rain water is highly corrosive, due to its acidity, high oxygen content, and lack of material which will form a protective deposit.

DISSOLVED OXYGEN

A steam boiler in operation is a fairly efficient degasifier, and may liberate into the steam space most of the dissolved gases in the feed water, particularly when evaporation is going on at a normal rate, and the feed water is introduced above the water line. Where a light protective deposit is formed, it is not necessary that the dissolved oxygen and carbon dioxide of feed water be reduced below a certain amount to prevent corrosion in the boiler proper. The amount of free oxygen in feed water which will cause noticeable corrosion in steam boilers usually varies from 0.05 to 1 cc. per liter.⁶ The amount permissible within these limits depends upon the

⁶ This depends upon the design and operating conditions of boilers. In large units operating at high pressure with evaporated water, the feed should carry under 0.05 cc. per liter of oxygen at all times.

acidity or alkalinity (hydrogen-ion concentration) of the water, and upon the nature of the feed water, i.e., whether evaporated water or water containing incrusting salts is used. The feed water should, of course, always be in the lower neutral or alkaline range.

Regardless of the theory of corrosion, experience indicates that the oxygen dissolved in the water is probably the greatest accelerator of corrosive action in boilers and accessories, and that it should be reduced to a certain minimum depending upon conditions.⁷

CARBON DIOXIDE

Carbon dioxide either free or half-bound as bicarbonates of calcium and magnesium, is usually completely removed by water treatment, or partially removed in open feed water heaters or deaerators. It has been shown that 35 per cent of the carbon dioxide of these bicarbonates is removed in a very short time when the water is completely deaerated under vacuum at from 140 to 160°F. (60 to 71°C.), with the result that the pH value was increased from 6.7 in the raw water to 8.7 in the deaerated water.⁸

A small amount of carbon dioxide has little influence on boiler corrosion proper, but may cause serious corrosion to steam pipes and other steam auxiliaries. This occurs only where condensation of the steam takes place because dry steam has no action on iron below about 650°F. (343°C.). However, where the water carries bicarbonates which have not been broken down with the elimination of carbon dioxide before the water enters the boilers, the boiler tubes may be severely attacked. Sometimes bicarbonate of iron is present. This and other bicarbonates can be partially decomposed and part of the gas separated in passing through an open heater operated at a temperature over 180°F. (82°C.).

Due to the separation of carbon dioxide, it frequently happens that the boiler water is decidedly alkaline, while the steam gives an acid reaction.

⁷ The various types of apparatus which have been developed for removing this and other gases have been described in other papers by the author ("Control of Corrosion by Deactivation of Water," *J. Franklin Inst.*, **193**, pp. 515-542, 1922, and "Water Deactivation," *Proc. Eng. Soc. West. Pa.*, **39**, pp. 189-201, 1923).

⁸ Jackson, D. H., and McDermet, J. R., "Effect of Deaeration of Natural Waters on the Carbonate Equilibrium," *Ind. Eng. Chem.*, **15**, pp. 959-961, 1923.

SALT, ALKALI, AND ACID CONTENT OF FEED WATER

It is a well-known fact that a certain amount of alkalinity will practically stop corrosion. *Higher alkalinity is required to inhibit corrosion with the higher concentrations of dissolved oxygen or of soluble salts* (figures 1 and 2). In distilled water, caustic alkalinity seems to

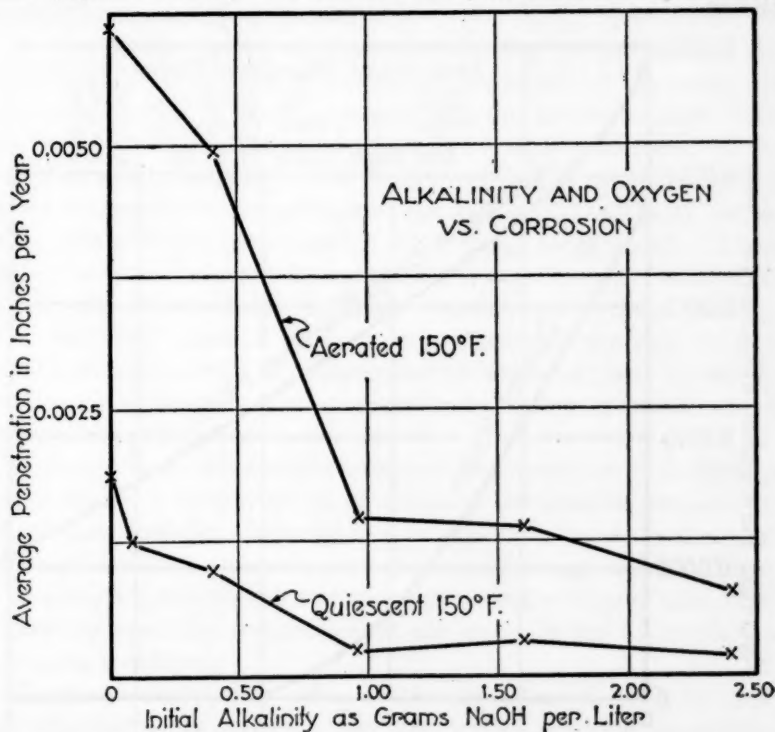


FIG. 1. INDICATING EFFECT OF OXYGEN ON RATE OF CORROSION IN DISTILLED WATER OF DIFFERENT ALKALINITIES

The quiescent water carried much less oxygen than the aerated water

have relatively more effect in reducing the corrosion rate as the temperature of the water increases. In high-pressure boilers using pure oxygen-free water, less alkalinity is required than is indicated by tests made at normal temperature where more oxygen is present. More experimental data are required to establish definitely this relation. At much higher concentrations caustic soda attacks the metal with generation of hydrogen and under certain rare water

conditions this appears to cause embrittlement of the metal. Unless the dissolved oxygen in feed water is under 1 cubic centimeter per liter, practical experience with stationary boilers shows that in most cases, the range of alkalinity which can be safely carried without causing foaming, or other trouble, will not prevent corrosion and pitting.

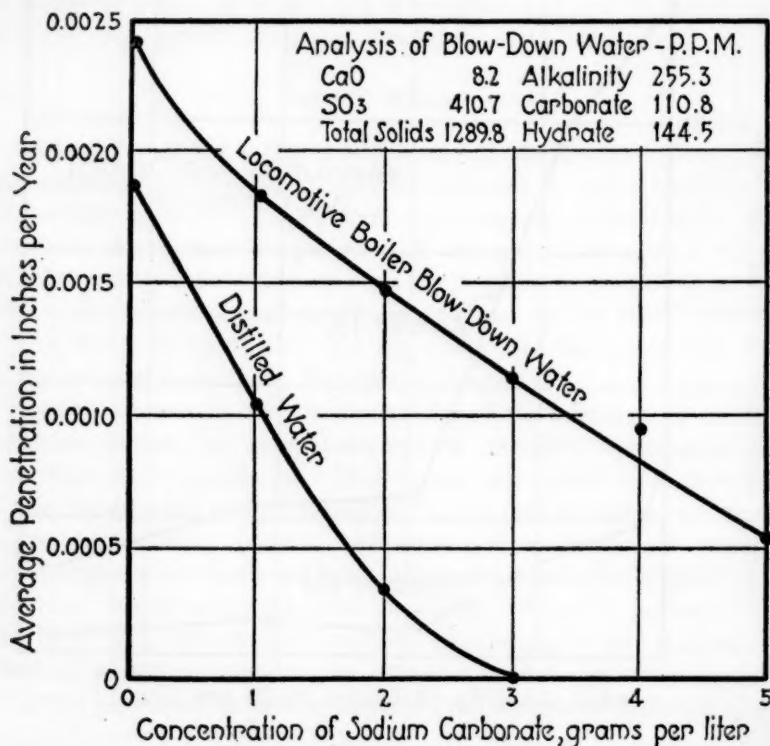


FIG. 2. INFLUENCE OF SOLUBLE SALTS ON RATE OF CORROSION WITH VARIOUS AMOUNTS OF ALKALINITY

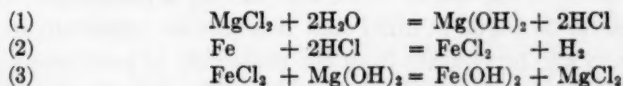
It has been shown that increase in pressure does not exert an appreciable effect on corrosion in water as long as the temperature, oxygen concentration, and other factors do not change. As the concentration of soluble salts increases, the water becomes a better electrolyte and, if sufficient free oxygen is available, conditions become more favorable to the formation of pitting. The electrical conductivity of water also increases with the temperature. Furthermore, variations in concentration may give rise to concentration

cells and localized corrosion (pitting). For these reasons, and to insure clean steam, it is desirable to maintain a relatively low and a fairly uniform concentration of soluble salts and alkalinity in the boiler water while under operation. These naturally increase rapidly when using a treated water, unless concentration is prevented by regular blow downs.

Evidently the oxygen content, scale-forming properties, and the hydrogen-ion concentration (acidity or alkalinity) of the water are the main factors in boiler corrosion and are closely related. The hydrogen-ion concentration may usually be allowed to rise until the water is nearly neutral, if the oxygen content is zero, but with a lower hydrogen-ion concentration (more alkaline solution), somewhat higher oxygen is permissible, other things being equal. These factors may be balanced in any way that appears most economical within the limits of concentration which cause serious foaming. The minimum amount of hydroxide alkalinity required in any particular case should be determined by corrosion tests in service as this is dependent on many variables the effect of which cannot always be predicted.

Although water is generally rendered less corrosive by increasing its alkalinity, a certain degree of alkalinity increases the tendency to pit, and an excessive alkalinity in water free from sulphates seems to be associated with embrittlement of the steel in the boilers. Hence, it is important to establish and maintain a certain range of alkalinity, depending upon the composition of the water in the boiler and an operating conditions.

Experience shows that waters containing sodium chloride by itself are not necessarily corrosive, but that waters carrying magnesium chloride are usually corrosive under boiler conditions. Furthermore, magnesium chloride is regenerative in its action, so that once the salt is brought into the boiler the corrosive action proceeds in a cycle, as indicated by the following reactions:⁹



In this way the amount of magnesium chloride tends to increase by

⁹ The hydrogen in reaction (2) may be oxidized to form water or may escape as a gas. The chemical reactions in a steam boiler occur in such extremely dilute solutions that the laws of ionic reactions apply.

concentration of the boiler water. In the absence of free oxygen the action continues, but is much less rapid. Magnesium sulphate and sodium chloride form a corrosive mixture and interact in the boiler to form magnesium chloride. Nitrate of lime and magnesium, when concentrated in the boiler, may generate nitric acid in the absence of excess alkalinity by a cycle of reactions similar to the chlorides. Many of the salts which cause permanent hardness are also corrosive, so that the treatment required to reduce hardness and scale formation minimizes corrosion from this cause.

Acid boiler water usually originates from the drainage of mines, swampy land, and industrial waste, or from the decomposition of magnesium chloride, especially under high boiler temperatures and pressures. Occasionally, when the water supply comes from marshy localities covered with thick vegetation, the water is polluted with mixtures of organic acids. These are volatile and, unless fixed by the addition of lime or similar reagents added for that purpose, result in impure and corrosive steam. The alkali used for this purpose does not increase the alkalinity of the water in proportion to the amount added, due to combination with the organic matter, but the condensed steam from water so treated is no longer acid.

Sulphuric acid may be generated in the boiler where the water has been previously treated with coagulants, especially alum, unless sufficient alkali is added to form stable sulphates and leave a residual alkalinity of about 17 parts per million in the feed water. Another source of acidity is from fatty acids derived from lubricating oil carried over to the heaters by steam from reciprocating engines using lubricants containing animal or vegetable oils. The decomposition of compounded lubricants takes place in a manner similar to that which occurs in the manufacture of soap from fats, liberating glycerine and fatty acids. The fatty acids are then free to attack the metal parts of the boiler. Since the animal or vegetable constituent is responsible for the corrosive action by lubricating oils, the best means of prevention is the use of lubricants having a pure mineral oil base. It should be borne in mind that it is just as important to protect the boilers and accessories from the possibility of acid attack as it is to obtain perfect internal lubrication. The use of mineral oils for lubrication will also minimize the tendency for the boiler to foam with the production of wet and dirty steam. Fatty acids combine with alkalies to form soluble soaps, which, when present in a soft water or when associated with dissolved salts of sufficient

concentration, may cause as much as 4 or 6 per cent of the feed water to be carried over from the boiler with the steam.¹⁰ When the raw feed water carries free acid, it should be treated near the source with soda ash or lime so that it will carry about 15 parts per million alkalinity in terms of calcium carbonate, in which condition it will not seriously attack the pipe lines and pumps.

INFLUENCE OF SCALE

The protective influence of scale which forms on the metal below the water line is a factor which plays a very important part in boiler corrosion. Excessive boiler scale, however, (particularly the sulphates and natural silicates) is objectionable, as it may greatly decrease the heat efficiency of the boiler and cause overheating of the tubes and shell. The presence of a more or less porous scale sometimes assists corrosion by increasing the temperature of the metal, producing a higher concentration of salts under the scale, and by favoring the decomposition of magnesium and other such compounds. For this reason, it is necessary in boiler-water treatment to consider both the control of scale formation and the removal of impurities which cause corrosion. Experience has shown that with an eggshell thickness of carbonate scale the oxygen contents of the boiler-feed water may be as high as 1 or 1.5 cubic centimeters per liter without serious damage to the boiler proper, but that with the use of 100 per cent evaporated water and no scale protection, a slight amount of corrosion is found even when the oxygen contents do not exceed 0.05 cubic centimeter per liter. A thin protective scale can be maintained, with a boiler water which otherwise would not form a protective scale, by the judicious addition of a certain amount of calcium hydroxide or sodium silicate. Such material should not be used unless the boiler water is tested regularly by a properly qualified operator.

In boilers, the corrosion that results from the decomposition of magnesium chloride, or other acid-forming salts, is the most serious because of the extensive pitting that often takes place underneath the scale before the corrosion is discovered. This action is sometimes exposed through cracks in the scale, which develop immediately over the affected areas due to the increase in volume of the products of corrosion. Where sufficiently pure water is not available, it is

¹⁰ Bradshaw, Proc. Eng. Soc. Western Pa., January, 1925.

important that proper treatment be used to completely eliminate all scale-forming and corrosive compounds and to maintain the correct balance between alkalinity and the other substances in solution.

Artificial protective coatings, such as special paints, afford only temporary protection to metal in contact with water at boiler temperatures. Any breaks in the coating tend to concentrate the action of the water at such places, so that if such coatings are used, they should be inspected at frequent intervals.

ORGANIC MATTER

It has been observed in practice that corrosion does not always occur when the feed water is untreated, and, as pointed out by Newman,¹¹ it seems to be less noticeable and, in fact, in some cases entirely absent where the organic content of the water is relatively high and where laboratory tests indicate a high consumption of oxygen by dissolved organic matter in the water.

The alkaline tannates, properly adjusted, are said to have the property of combining with dissolved gases, particularly with oxygen.¹² It has been stated that organic matter tends to prevent the decomposition of soda ash in boilers.¹³ A few tests in a laboratory boiler did not show this retardation with tannic acid or sugar.¹⁴

INFLUENCE OF COMPOSITION OF THE MATERIALS OF CONSTRUCTION

Charcoal iron and low-carbon bessemer and open-hearth steels have been used for boiler construction with very little difference in the rate of corrosion or pitting. Bessemer steel, however, is not now used in important parts of boiler construction on account of the tendency to develop brittleness in service as a result of fatigue. It is difficult and costly at present to make boiler tubes of corrosion-resistant metals, such as high-chromium iron or the nickel-chromium alloys. Until tubes can be made of a material decidedly better than low-carbon basic open-hearth steel, there will be little advantage in making other parts of the boilers of these more expensive steels, as

¹¹ Abstract of Discussion by M. F. Newman of Paper by Speller, F. N., "Water Deactivation," Proc. Eng. Soc. Western Pa., **39**, pp. 189-201, 1923.

¹² French, D. K., "Internal Treatment of Boiler Water—Proper and Improper," Ind. Eng. Chem., **15**, pp. 1239-1243, 1923.

¹³ Rice, C. W., private communication.

¹⁴ Karch, H. S., and Hall, R. E., private communication.

the tubes are the vulnerable parts and usually the first to fail. It seems at present, therefore, that the solution of the corrosion problem in boilers lies in the removal or control of the causes of corrosion. Generally speaking, this is not a very difficult problem.

PREVENTIVE MEASURES

Boiler-water treatment in general¹⁵

Some of the harmful gases in boiler-feed water are driven off by heating in feed-water heaters or deaerators, but others can only be removed by chemical treatment. The best control over boiler water is naturally obtained by the use of evaporators and distilled water (with deaeration) but there are, of course, many places where this practice is impracticable or unnecessary. In modern, high-pressure stationary steam plants, however, the difficulties due to poor quality water are so serious that the use of distilled water, with every precaution for excluding air from the system, is becoming more general. In fact, where high-pressure stationary boilers are operated at 200 per cent rating or higher, a water free from incrustants is considered to be necessary. Under these conditions, where the per cent of make-up water in the feed supply is small, it usually pays to install evaporators.

In smaller plants, operating below 150 pounds pressure and at low rating, it is sometimes most economical to treat the water on its way to the boiler and carry out the reactions in the boiler itself, thus avoiding the expense of boiler-water treating equipment. When the precipitated matter which results from internal treatment of feed water causes an undesirable amount of water in the steam, the additions should be made and the reactions completed outside of the boiler. The equipment for external treatment should be of sufficient capacity to permit the maximum precipitation and separation of suspended matter and scale-forming and corroding compounds before the water enters the boiler. In most cases, sufficient saving can be shown in increased efficiency of operation to warrant external treatment by one of the systems developed for this purpose. The basic

¹⁵ This section is not intended to cover all details of boiler-water treatment. As prevention of scale and corrosion are closely allied subjects, however, they are outlined together. Further details may be had by reference to the methods of procedure recommended in "Suggested Rules for the Care of Steam Boilers in Service," Am. Soc. Mech. Eng. Boiler Code, Sec. 7.

principles of these systems involve the use of lime and soda ash, or some similar chemical, and the results obtained have been well-established and proven by experience.

In general, a properly softened boiler-feed water is one in which there is no permanent hardness, in which the calcium and magnesium carbonates have been reduced to a minimum, and in which the total alkalinity (by methyl orange), due to sodium carbonate and hydroxide, is from 25 to 50 parts per million (according to the temperature of the treating tanks).

The water should be treated to eliminate unstable salts of magnesium or calcium and should carry sufficient excess of total alkalinity to prevent the formation of corrosive acids in the boiler. Alkalinity, due to calcium carbonate, is not sufficient to prevent acid corrosion, as it will not stop the decomposition of magnesium chloride, or of calcium chloride formed by the interaction of calcium carbonate and magnesium chloride. In such cases, full protection against corrosion can be obtained only by the application of a soda ash treatment to convert the magnesium chloride to the neutral and stable sodium chloride.

In stationary and locomotive practice, it has usually been found economical to remove scale-forming and corrosive matter from the feed water before it enters the boiler. This may be done in nearly every case by the use of soda ash and lime, either by the intermittent or by the continuous process.

The recommended procedure for obtaining the proper chemical treatment of a boiler-feed water is to: (a) make a complete technical analysis of the feed water; (b) determine the amount and kind of treating chemicals required and the best system of treatment; and (c) procure reagents and apparatus for carrying out the treatment and making the necessary control tests. This requires the services of an experienced industrial water chemist.

Passivifying agents, such as the chromates, are not adapted for boiler use as passivity is destroyed by heat. Furthermore, the chromates react with soluble chlorides to produce free hydrochloric acid, so that in some natural waters their use might cause acid steam.

Boiler compounds of unknown composition should not be used for the treatment of boiler water. The basis of any successful treatment is a detailed knowledge of the objectionable materials in the water and the influence of the products of the treatment on the operation of the boiler and the quality of the steam. The recommendation

of experienced concerns who manufacture boiler-water compounds may be helpful after they have had an opportunity to examine analyses of the water requiring treatment.

Special application of water treatment to various kinds of steam boilers

While the general conditions which cause corrosion in boilers may frequently be the same, there are three main fields of boiler service and treatment which vary sufficiently from each other in practice to warrant separate discussion in respect to some details. These are found in the treatment of water for stationary, locomotive, and marine boilers.

The previous discussion applies to boiler practice in general. The problem in the case of stationary boilers, however, is not usually complicated by having to obtain feed water from a number of sources as in locomotive and marine practice, so that the treatment is comparatively easy to control. Hence, it is not surprising to find that, as a rule, much better results are obtained in stationary practice than in other classes of boiler service.

Deaeration of feed water has been well developed for stationary boiler practice and in most cases, so far as the boiler itself is concerned, sufficiently good results will be obtained by the use of properly vented, open feed-water heaters of sufficient capacity.

The position at which the feed water is introduced into the boiler has a marked influence on corrosion. It is much better to release the feed water a little above the high-water level, so that it flows lengthwise in a long open tray or over pans placed in the steam drum. This further preheats the water to some extent and gives the dissolved gases an opportunity to be released into the steam space before the new water has time to diffuse downward in the boiler and to come in contact with the metal. Where such apparatus is omitted or not properly installed, the oxygen immediately below the feed-water entrance is higher than elsewhere in the boiler. This, with the greater circulation downwards immediately below the feed entrance, causes greater corrosion on these tubes than elsewhere in the boiler.

Although the temperature of feed water is much lower than in the boiler water, pipes carrying hot feed water to the boiler are usually much more subject to corrosion than the boiler tubes, due to the relatively higher oxygen contents of the feed water. If the feed-water inlet is so placed as to permit the water to impinge on any

metal part of the boiler, rapid corrosion is certain to occur at such places unless the water is free from dissolved oxygen.

The velocity of circulation in a high-pressure boiler is very high. While most of the oxygen is discharged in the steam drum, some of it will be carried along with the boiler water, and will cause corrosion. Feed water carrying dissolved oxygen should not be added to a boiler which is not steaming as it will diffuse through the boiler and cause corrosion. The water in a boiler should, therefore, be brought up to the proper level while it is in operation.

The viscosity of water decreases considerably with increase in temperature. This, with the high velocities of water in modern boilers operating under high rating, probably tends to increase corrosion by bringing the main body of the water into closer contact with the metal, thus sweeping away surface films (liquid and solid) which otherwise might exert a marked protective effect.

Steam in the absence of oxygen

Steam in the absence of oxygen attacks iron to a very slight extent at 650°F. (343°C.). The action increases rapidly with the temperature so that serious damage may result in time at temperatures around 1200°F. (649°C.). It has even been shown that in steam boilers, with an oxygen concentration in the water of less than 0.1 cubic centimeter per liter, a small amount of gaseous hydrogen (under 0.1 cubic centimeter per liter) is evolved at a temperature of 585°F. (308°C.). The amount of gaseous hydrogen evolved increases with the temperature within certain limits not yet fully defined. In this connection it is interesting to note that pure water at 650°F. (343°C.) has a pH of 5.5.

The action of steam on iron at high temperatures produces magnetic oxide of iron according to the reaction:



This is becoming a more important practical consideration, due to the present tendency toward higher pressures and superheating in modern steam power plants. Already signs of deterioration have been observed in steel superheater tubes. It has been found that steel, wrought iron, malleable iron, and white and gray cast iron are all subject to attack, but the high chromium and nickel-chromium-iron alloys are much more resistant under these conditions.

Superheaters

For iron pipes which convey pure dry steam, and are not externally heated, experience indicates that no deterioration of the metal is to be feared up to 1000°F. (538°C.), or probably a little higher. For conditions where heat is being transferred to the steam (as in superheater units), and where the tubing is not subjected to high gas temperatures at times when no steam is flowing through the tubing, seamless steel tubing has shown practically no oxidation up to 800°F. (427°C.) steam temperature. The extent of deterioration of pipe at high temperatures also depends upon other variables such as: the amount of excess air in the products of combustion, the amount of corrosive sulphur compounds in the gases, the velocity and temperature of the gases, the impingement of flame, and the abrasion due to solid particles in the gas stream. These factors at the present time are responsible for much more deterioration than the temperature of the steam.

Locomotive practice

The design and construction of locomotive boilers, the composition of materials entering into their construction, and their mechanical operation, have reached a high stage of development. The chemical and physical properties of the plates and tubes used are so regulated by rigid specifications that the quality of the material is well above the average. The development of improved steel may have had some influence in prolonging the life of locomotive tubes, which are naturally the vulnerable part of the boiler. It must not be forgotten, however, that locomotive boiler service is usually the most severe of all. The treatment of locomotive water to stop corrosion is more difficult to control and is complicated by factors not present in stationary boiler practice. The alkalinity cannot usually be carried high enough to inhibit corrosion when the water is high in oxygen without causing foaming, and so far no practical apparatus has been developed to eliminate enough of the free oxygen from locomotive feed water to stop corrosion. It has been frequently noticed that stationary boilers show no pitting or corrosion after 15 years or more, whereas locomotive boilers, using the same water, may show serious pitting after 2 or 3 years.

Boiler corrosion may be practically eliminated as a general rule if the hydroxide alkalinity is kept over 100 parts per million and the

oxygen content of the feed water is reduced to 1 cubic centimeter per liter or lower. As pointed out above, this degree of deaeration is usually accomplished by open heaters with stationary boilers, but the application of this type of heater or deaerator to locomotive service presents serious practical difficulties. Any feed-water heating or deaerating apparatus designed for locomotive use must, of course, be comparatively small and compact, and should heat all the water up to the boiling point or higher. So far feed-water heaters for locomotive service have been designed mainly to give greater thermal efficiency. With this may be combined an important increase in the life of boiler tubes if a considerable portion of the air is removed. A practical form of locomotive feed-water heater is badly needed; one which will not leave more than 1 cc. per liter of dissolved oxygen in the feed water is required.

Some experiments conducted by the author with the use of a vacuum deaerating tank in the tender of a locomotive resulted in the removal of 35 per cent of the oxygen from the feed water at 76°F. (24°C.) with a vacuum of 8 inches of mercury. Under these conditions, there was a residual oxygen content of 4 cubic centimeters per liter. It was found that to reduce the oxygen to 1 cubic centimeter per liter a vacuum of 20 inches and a temperature of 125°F. (52°C.) would have to be carried. It was found impractical, however, to start an injector in operation at a temperature as high as 100°F. (38°C.) with a vacuum of over 4 or 5 inches so that for this purpose a feed-water pump seems necessary whether the water is deaerated in an open heater at the boiling point under atmospheric pressure, or in a deaerator at a lower temperature and pressure.

As pointed out above, the position at which the feed water is introduced into the boiler has an important bearing on the proportion of the free oxygen which is retained in the water and is available for corrosion of the boiler. This point should receive careful consideration in connection with locomotive boilers where the feed water is usually delivered to the boiler nearly saturated with oxygen.

Although locomotive boilers are subject to a much wider variety of water and more strenuous service than stationary boilers, as a rule less attention is given to water treatment, particularly by the smaller railroads. This is also true with respect to the development of feed-water heating and deaeration which is so essential and might easily treble the life of locomotive boiler material.

OTHER GENERAL PRECAUTIONS FOR CARE OF BOILERS

Water treatment for new boilers

During the construction and installation of new boilers, more or less grease finds its way into the plates and tubes. This should be removed by adding $2\frac{1}{2}$ pounds of soda ash per 1000 gallons of water and boiling with a slow fire at atmospheric pressure for a period of at least 48 hours. After emptying the boilers they should be thoroughly washed out with clean water applied by a hose at high pressure.

The clean unprotected metal is likely to corrode rapidly as, for example, in new boilers or in boilers which have been re-tubed or turbinized. After the boilers have been thoroughly cleaned, by the above method, about 10 pounds of lime for every 30,000 pounds water capacity should be mixed with the cold feed water and run into the boiler, and from 4 to 6 pounds of lime, as milk of lime, for every 30,000 pounds water capacity should be added each day for not longer than six days. Milk of lime is a mixture of about 1 pound of unslaked lime, or $1\frac{1}{3}$ pounds of hydrated lime, with 1 gallon of water. Lime additions are made, as a rule, only when the boilers are new or after re-tubing. The lime treatment should be completed before any other treatment is applied to the water. Lime is soluble to about 90 parts per million at 200 pounds boiler pressure (382°F.), so that the excess over this amount will be deposited as a soft scale on the metal or as sludge.

The action of the water is concentrated on areas from which the mill scale has been removed and, if this is a small proportion of the whole surface, pitting may result. More uniform corrosion and longer life of the tubes may be obtained by first pickling them free from scale, and then washing them in warm water and in milk of lime before they are installed.

Internal protection

When boilers are first filled the water should be boiled under atmospheric pressure using a direct fire and agitating the water by means of circulators or, in the absence of circulators, the water should be simply boiled for a short time under atmospheric pressure before the boilers are closed.

Pump glands in suction lines should be tight enough to avoid drawing in air. All feed-pump suctions should be entirely covered with water at all times, and all discharge lines should be scaled.

If all oil cannot be removed from the feed water by mechanical means, the lubricating oil should be analyzed for fatty compounds, and if these are present, straight mineral oil should be substituted.

Defective circulation and unequal strains in the boiler metal tend to promote local corrosion.

Electrolytic action often occurs where copper and brass pipe or fittings are fastened to the boiler structure or where copper ferrules are used, and this may cause local accelerated action on the steel unless an insulating scale is formed by the water.

Where pitting has occurred, the pit holes should be thoroughly cleaned out and filled in with zinc oxide paste. Where only a small number of deep pits occur, these may be cleaned and filled in by electric or acetylene welding, when this practice is not prohibited by insurance or other regulations.

The boiler should be blown down as often as necessary to keep the concentration of dissolved salts fairly uniform and at a safe value. When the boilers are taken out of service, certain precautions should be taken to prevent corrosion. They should be emptied and dried by means of a light wood fire. About 20 pounds of quicklime for each 100 horsepower should be placed on wooden trays in the interior of the boiler, after which all connections should be tightly sealed. Where the boilers are idle for a considerable period they should be opened every 3 months for examination and renewal of the lime. If water is left in idle boilers it should be made alkaline with caustic soda in excess of 50 grains per gallon and the water level should be raised up to the safety valve. The number of pounds of soda required equals the rated horse-power multiplied by 0.7. Caustic soda should be first dissolved and then added through the top main header into a full boiler of water, after which all openings and connections should be made tight. A piece of bright iron should be hung in the boiler in such a manner that it can be removed and inspected at regular intervals to determine whether or not the treatment is sufficient to stop corrosion.

CONCLUSIONS

The more important preventive measures which may be applied to protection of steam boilers may be summarized as follows:

1. Reduction of free oxygen to the lowest limit practicable. This combined with the right alkalinity has an important bearing on the control of the tendency of metal to corrode and pit.

2. The maintenance of a sufficient amount of hydroxide alkalinity to prevent corrosion and pitting. The amount required decreases as the residual free oxygen is reduced, and is also dependent on the concentration and kind of salts in solution. As there are so many factors involved, the correct alkalinity required should be determined, for the present, by tests on concentrated boiler water under service conditions as nearly as possible.

3. The scale-forming salts should be kept under control by proper water treatment so as to give only a light protective scale; pitting sometimes occurs under certain kinds of thick scale. Proper treatment of the water when the boiler is first filled is particularly important to avoid initial corrosion.

4. The best grade of material should be employed throughout. The tubes should preferably be pickled free from rust and mill scale, and washed in milk of lime before installing.

5. A counter-electromotive force may be imposed on the parts to be protected (as by the Cumberland system or by firmly attaching zinc slabs to the boiler shell), but these expedients present some mechanical difficulties in application and unless properly installed and maintained are of little or no use.

6. As dissimilar metals in contact tend to accelerate the corrosion of the one that happens to be anodic, and retard the action on the other proportionately, it is preferable, where corrosion cannot be entirely prevented, to have important parts cathodic to other parts the corrosion of which is not such a serious matter. It is especially desirable to avoid using an anodic or electropositive metal for small parts such as rivets as the action in such cases will be concentrated on a relatively small area and may cause serious results in a comparatively short time, whereas when the larger area is the anode the depth of penetration in a given time will be extended in proportion to the relative areas of the surfaces in contact. Copper-bearing steel is slightly cathodic (or electronegative) to non-copper-bearing steel and may be useful in certain cases, such as for rivets or tubes, where it is desirable to control the relative potential of the various parts of the boiler. The author has found low carbon steel carrying 0.5 to 1 per cent copper to be much more resistant than soft steel of lower copper contents, in certain kinds of highly concentrated salt water. As this alloy is not very expensive and has good physical properties, it may find a useful application in boiler construction.

7. The water treatment should have sufficient expert supervision

with analyses at regular intervals and check corrosion tests on samples inserted in the boiler.

From the foregoing review of the facts and factors involved in steam boiler corrosion, it seems that deterioration from this cause can usually be controlled at a reasonable expenditure, under proper supervision. Compared with the amount invested in steam power plants, the extra outlay required to minimize or prevent corrosion is usually a relatively small item and one on which a relatively large return may be expected.

Much has been done during the past ten years in the study of the many factors involved in corrosion. It has been found that the ordinary variations in composition of iron or steel and other factors inherent to the metal, such as strain, grain size, metal structure, etc., are of minor importance compared with the influence of dissolved oxygen, the contact of dissimilar materials or solutions, and many other factors external to the metal. It has also been shown that corrosion may be classified into several different types, each one being controlled by a different set of external factors so that the problem as a whole is evidently very complex. In any one type of corrosion, however, such as in steam boilers, it appears that only a few factors exert a controlling influence. It may be expected therefore that much more progress will be made in the practical solution of the corrosion problem as a whole, when those most interested in each phase of the subject arrange to organize their investigation work together under the control of a responsible working committee. The committee now in process of organization by the American Water Works Association, in conjunction with the American Railway Engineering Association, National Electric Light Association, and American Society of Mechanical Engineers, for the study of boiler feed-water treatment would seem to be the natural sponsor for this phase of the work. The actual research work in the laboratory and in the field should be done by competent assistants who can devote their *entire time* to working out the details of the plan of investigation. The Refrigerating Industry has recently started a systematic investigation of their corrosion problems in this way and already the results of this concentrated effort point toward a practical solution of many of these problems. As a fundamental step towards the solution of the corrosion problem with respect to locomotive and stationary boilers, the following suggestions are offered: (1) that this problem be placed in the hands of an active committee who will be strongly sponsored

and supported; (2) a definite working program should be laid out involving a study of the work already done, new laboratory research (particularly on the pitting of iron), and the testing of preventive measures in practice; (3) sufficient funds should be raised to carry out such a program over a period of at least three years. It is the belief of the writer that with such an organized effort much may be accomplished towards a practical and economical solution of this problem.

Considering the great economic loss due to corrosion and the general interest in this subject, it would seem logical and most economical for each of the large industries interested to appoint responsible working committees with experienced assistants as suggested above, and then tie these committees together by means of a central advisory committee so as to pool all the results and avoid overlapping of research work. In this way it seems that the best results may be expected with the least expenditure of time and money.

BOILER ROOM ECONOMY¹

By A. W. COLE²

1. A manufacturer generally considers the power plant a necessary evil. It is therefore ignored if the necessary power is forthcoming. Nevertheless the boiler room and power plant are the sources of one of the greatest expenses involved in any manufacturing process. You continually shovel money into the furnace.

2. Heat is nature's greatest natural resource, for without it nothing could exist. Heat is a real natural resource and is stored for our future use in many latent forms in nature. Fuel in the form of coal is the most important source of easily available heat. Coal is no longer being formed upon our earth and this source of heat can never be replaced. This source of heat, so necessary for all human comforts and welfare, should be conserved for future generations, as well as for our own future welfare. This fact is ignored by most power plant operators, much to the detriment of themselves and others.

3. The power house is where such conservation can, should, and must be made by providing:

- a. Good boilers of the best design.
- b. A well and properly set boiler.
- c. Proper equipment in the form of instruments, stokers, scales, to measure and judge the performance of the boiler.
- d. Well kept surroundings and proper working conditions for the men.
- e. Proper machinery in which to use the steam after it is produced.
- f. Proper use made of the exhaust.
- g. Men possessing knowledge of heat engineering and enthusiastic in the plant, its equipment and its operation.
- h. Taking stock from time to time by proper tests made by competent engineers.

4. *Good boilers:* A boiler will not wear out, but will become out of

¹ Abstract of paper presented before the Indiana Section meeting, March 26, 1926.

² Professor of Steam Engineering, Purdue University, Lafayette, Indiana.

date. Progress is so great that no one can expect to use old equipment with efficiency.

5. *Boiler settings*: Should be properly designed. Combustion requires good mixtures, adequate air supply, sufficient temperature and time enough to complete the combustion process. A good setting should provide these by giving proper and ample volumes in the combustion spaces, long enough gas passages, proper draft, and protecting the setting against radiation and air leakage. All excess air will mechanically absorb heat and carry away heat causing a useless waste. This approximately equals 0.24 B.t.u. per pound per degree.

6. *Equipment*: Should include a properly designed stoker taking into account the fuel to be used. In addition there should be apparatus for determining temperature of stacks, steam, and draft air, amount of air used, and amount of coal fired, with the corresponding water evaporated. This is necessary in order that you may know what heat you are receiving from your investment in coal.

7. *Pipe coverings*: B.t.u. per square foot of raw pipe per degree differences 2.75 or 2.8 B.h.p. for each 100 sq. ft. of pipe per hour, where for covered pipe it should be nearly negligible.

8. *Draft regulation* is essential for control of excess air, flue temperature, etc.

9. CO₂ recorder will tell how well your coal is being lowered and therefore your income in heat for your outlay in fuel.

10. A clean plant is an inspiration to the workers and a source of pride to the owner.

11. A modern plant implies employers of ability which implies the encouragement of education among the force. This in time provides loyalty, and loyalty means economy.

12. It has been said: "What you don't know will not hurt you." Is this true as regards continual "leaks" from the profits that you do not know about?

Is it true you are plodding along with poor and insufficient equipment losing money day by day?

Have you a boiler on the line which should be cleaned or repaired, thereby losing money?

Is it true that you do not know whether your plant is showing a profit or loss?

13. Twelve reasons why your plant should be in perfect running order:

a. It will mean money to you in the saving of fuel.

b. It will put your plant on a better business basis.

c. It will improve your standing with your employees, with supply houses, and all others with whom you do business, or hope to do business.

d. It will give ease of mind for you can be assured that at all times power will be available, and will thus enable you to use your wits on energies in building up your business.

e. It is the most effective method known of making a difficult job easy.

f. It will improve your standing with your fellow men.

g. It is effective because it enables you to know the true condition of your business at all times. Your business is no stronger than its motive forces.

h. It enables you to estimate your future power costs.

i. It enables you to have a better understanding with your employers, thereby promoting harmony in your plant.

j. It will help in making estimates by referring to similar work done.

k. It will assure you of financial success if coupled with properly applied efforts.

l. It will increase your peace of mind, and your personal happiness, for you will be in a more cheerful frame of mind at the close of each day's efforts.

14. You balance your books at frequent intervals, but do you carefully balance the heat account of your power plant?

Can you tell how much of your heat is going into your production?

Can you tell where all of the remainder goes?

Can you find the leaks through which you are losing heat?

In other words, will your heat account balance as does your financial account?

It should and will if at periodic intervals you will have your plant tested by some one competent to measure your heat distribution and losses. Then if you will gradually build up your plant under competent advice together with loyal and enthusiastic employees, your efficiencies will go up and your costs go down to the advantage of yourself, your employees, and the community at large.

THE POLLUTION OF LAS ANIMAS RIVER¹

By DANA E. KEPNER² AND PAUL S. FOX³

The need of this investigation was brought to our attention by the endemic prevalence of typhoid fever along the Animas and San Juan Rivers. There are very few wells in these two river valleys which produce a potable water and consequently most of the water used by the inhabitants is obtained from the irrigation ditches. The water in the Animas is usually clear and cold and fairly soft.

The Animas River rises in the mountains of southwest Colorado a few miles above Silverton, Colorado, and flows in a southerly direction to its confluence with the San Juan River. Both Silverton and Durango, Colorado, discharge untreated sewage into the Animas. Because of this fact, it was deemed advisable to conduct a series of bacteriological examinations on samples of Animas River water collected at various points.

A field laboratory was established at Aztec, New Mexico. This point was chosen because it was more or less centrally located and because natural gas was available for use in the laboratory. Only one man was available for the entire work, so it fell upon him to collect samples and to do the necessary laboratory work. All of the bacteriological work was done in accordance with the procedure as outlined in "Standard Methods of Water Analysis, 1923" by the American Public Health Association.

Samples were collected in sterilized glass stoppered bottles and carried in iced containers. An automobile was used for transportation. Samples were taken in five different series over a period of a year as follows: November 18 to 23, 1923; February 8 to 16, 1924; May 13 to 21, 1924; August 15 to 23, 1924; and November 8 to 13, 1924.

Compilation of all of the information collected indicates the following:

¹ Presented before the Rocky Mountain Section meeting, February 23, 1926.

² Sanitary Engineer, Colorado State Board of Health, Denver, Colo.

³ Division of Sanitary Engineering and Sanitation, New Mexico Bureau of Public Health, Santa Fe, N. M.

1. The sewage of Silverton, Colorado, is of little importance to communities lower down the valley, due to the excellent purification which takes place before it reaches Durango.

2. Durango introduces untreated sewage into the river which gives an average total count of 743 bacteria per cubic centimeter and 11,700 *B. coli* per 100 cubic centimeters. At Riverside, New Mexico, these figures are reduced to 246 and 1280, respectively. This shows a marked degree of self-purification. From Riverside to Farmington the total count increases from 246 to 542 per cubic centimeter and *B. coli* decreases from 1280 to 695 per 100 cc. These results indicate the marked and rapid self-purification of the stream. However this is usual in swift mountain streams of this character. Due to the rapid flow of the stream, and considering that *B. coli* is present in the water at Aztec and lower points at times, we are justified in believing that the discharge of untreated sewage by Durango into Las Animas River constitutes a nuisance and menace to public health.

3. It would seem possible that an irrigation ditch flowing through an inhabited section would pick up considerable pollution. Our findings do not substantiate this belief. Station 7 shown in figure 1 is the head of the Lower Animas ditch. The average count was 191 bacteria per cubic centimeter and 600 *B. coli* per 100 cc. Station 13 was on the same ditch at Aztec, perhaps four miles below the head-works. The average total count, 988 bacteria per cubic centimeter and 126 *B. coli* per 100 cc. That there is a reduction in *B. coli* is a remarkable fact, due to the many possible sources of pollution such as barnyards and corrals. The increase in the total count is probably due to decaying vegetation along the bank of the ditch.

4. Colorado citizens living in Las Animas Valley below Durango are also practically dependent upon Las Animas River water for domestic use. The results of this investigation indicate that the river in this section is highly polluted and unsafe for domestic consumption without proper filtration and sterilization.

The authors recommended that:

1. The city of Durango immediately take steps leading to the installation of a sewage treatment plant. It is our opinion that sedimentation will suffice for the immediate future, and that a properly constructed and operated Imhoff tank will answer the purpose. In making this recommendation, we have agreed upon the following policy: A stream forms the natural drainage for a community and

therefore should be reasonably used as such. Due to the pollution which is accumulated from reasonable human occupancy of the watershed, it cannot be expected that the river water will be safe for domestic consumption without treatment of some sort. However, in the light of present day knowledge we believe that the pollution introduced by the city of Durango constitutes an unreasonable use of the stream. We also believe that the self-purification ability

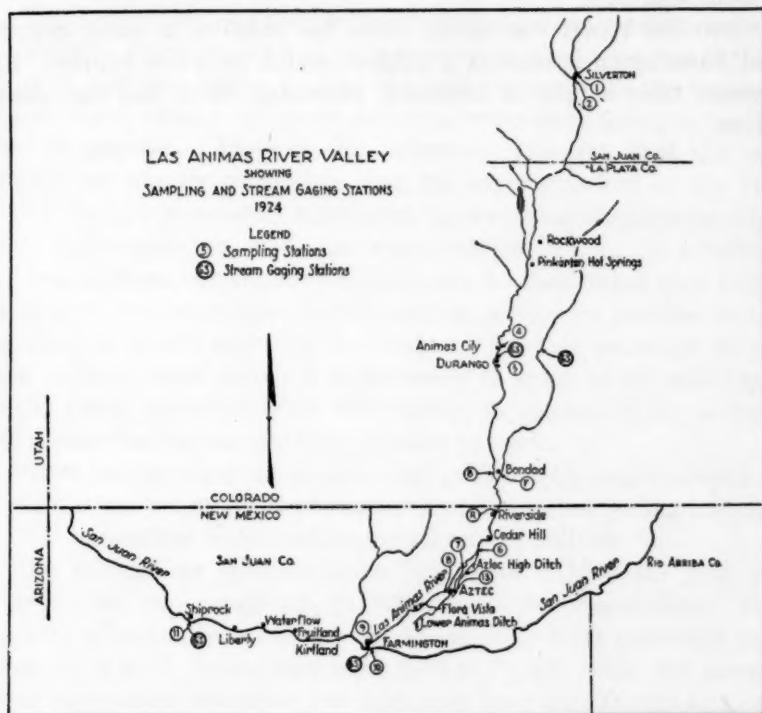


FIG. 1

of the stream should be utilized, as far as is safe, in consideration of the present use of the water for irrigation and domestic use. We consider that this self-purification is of such importance that it will be unnecessary to have secondary treatment of the sewage.

2. The New Mexico Bureau of Public Health continue, and the Colorado State Board of Health start giving publicity to the method for treatment of ditch water at time of filling the cisterns, so that it will be safe for consumption. It is recognized that even with what

we consider adequate treatment of Durango's sewage, the river water will not be safe for domestic consumption without treatment, although its sanitary quality will be much better than at the present time.

3. The town of Farmington take such steps as are necessary either to find a new water supply; or to install a modern filtration plant with chlorination of the filtered water, to be used in connection with the present source.

Since this report was made, Aztec has installed a water system and Farmington is making a diligent search for a new supply. At present their supply is obtained, untreated, from the San Juan River.

THE ILLINOIS CENTRAL'S WATER SUPPLY¹

BY C. R. KNOWLES²

The duties of a city water works superintendent or manager and the duties of a superintendent of railway water service are along parallel lines to a certain extent, as they are both charged with the responsibility of providing an adequate supply of water satisfactory in quality for all purposes. There is this difference, however, that the city plants are usually so located that the superintendent of the city water works is in constant touch with them and has direct supervision over their operation, while the water service stations on a railway system, such as the Illinois Central, may be distributed over half a continent and are subject to the varying conditions peculiar to the territory in which they may be located. For this reason in discussing railway water service it is necessary to speak of the water stations, either individually or collectively, in general terms as each particular station has problems peculiar to itself.

There has been a great development in Illinois Central System during its seventy-five years of existence and a corresponding increase in the demand for water and improved water facilities.

The mileage has increased from 705½ miles in 1856, the year the charter lines were completed, to 6500 miles at the present time. The number of locomotives has increased from 83 to 2000, passenger cars from 52 to 2000, freight cars from 1249 to 70,000, while the investment in railway properties has increased from \$26,000,000 to more than \$600,000,000.

The contrast between the first water stations on the Illinois Central is quite as marked as the other developments in the road, as when the railroad was first established water was pumped directly to the tenders of locomotives by hand pumps which were later followed by small tanks from 1000 to 5000 gallons capacity and the water delivered to the locomotives by leather spouts. These roadside tanks were in some cases filled by hand pumps and in others by horse power, de-

¹ Presented before the Illinois Section meeting, March 25, 1926.

² Superintendent, Water Service, Illinois Central System, Chicago, Illinois.

pending upon the demand for water. The hand and horse power driven pumps were in time replaced by windmills and hot air engines which were in turn replaced by steam pumps and gasoline engines, gasoline and steam driven pumps predominating up to within the last twenty years or so, while modern equipment consists largely of oil engines and electric driven pumps.

The size of the tanks increased from the first tanks of 1000 gallons capacity to tanks holding 15,000 gallons in 1870, and at the close of the last century the size of roadside tanks had increased to from 50,000 to 100,000 gallons capacity. Today with locomotive tenders having a capacity of from 12,000 to 16,000 gallons, standard main line roadside tanks have a capacity of from 100,000 to 200,000 gallons.

Our Centralia, Illinois water station offers an example of the increased demand for water on the Illinois Central during the past seventy-five years. The first tanks erected at Centralia at the time the road was completed had a capacity of approximately 5000 gallons as Centralia was a terminal and the demand for water was heavy as compared to outlying stations. The daily consumption of water was from 20,000 to 25,000 gallons. We now have four tanks at Centralia with a combined capacity of 350,000 gallons, the daily consumption of water being 1,000,000 gallons.

The road operates in fourteen states of the Mississippi Valley, namely, Alabama, Arkansas, Illinois, Indiana, Iowa, Kentucky, Louisiana, Missouri, Mississippi, Minnesota, Nebraska, South Dakota, Tennessee and Wisconsin, the main line of the system extending from Chicago south to New Orleans with numerous branches in Illinois, Kentucky, Alabama and the Mississippi Delta. A line also extends westward from Chicago across Illinois and Iowa to Omaha and Sioux City on the Missouri River with another line from Cherokee, Iowa to Sioux Falls, South Dakota.

Illinois Central System locomotives ran 56,000,000 miles in 1925, hauling 35,000,000 passengers and 69,000,000 tons of freight, using in excess of 12,000,000,000 gallons of water. In addition to this amount approximately 900,000,000 gallons were required for stationary boilers and approximately 3,000,000,000 gallons for other purposes, making a total of 15,900,000,000 gallons. Of this amount approximately 4,000,000,000 gallons were purchased from municipalities, the remainder being pumped by railroad pumping plants.

The water comes from various sources. The supply at 134 points

is obtained from wells ranging from 2 to 60 grains hard, that at 144 points is obtained from streams, principally the Mississippi River and its tributaries, but including several fluctuating streams polluted with mine drainage. The water at 14 water stations comes from lakes, at 13 from springs and at 34 stations from reservoirs, thus constituting in all 339 water stations. Of these stations 99 are supplied with city water and 40 stations are equipped with filtering or softening facilities which range in capacity from 10,000 to 50,000 gallons per hour.

Covering such a considerable portion of the country as is served by the Illinois Central means that the railroad must make use of a large variety of waters the greatest part of which is used in locomotives. It follows therefore that the selection of a satisfactory water supply or the treatment of an unsatisfactory water supply is of the utmost importance in locomotive operation.

The waters on the Southern Lines of the Illinois Central are with few exceptions among the best boiler waters of the country. The exceptions are where the surface waters carry large quantities of mud and other matter in suspension and where the well waters are low in dissolved content and the elements in the water are not properly balanced. These waters are commonly classed as "too pure." For example, a condition of this kind exists on that part of the Tennessee Division from Fulton, Kentucky to Birmingham, Alabama. In order to overcome corrosion and pitting from the use of this water it is necessary to add certain impurities to the water in the form of compounds. The purification of most of the Southern waters is largely a matter of filtration and removal of mud. For example, at Baton Rouge, Louisiana, the Mississippi normally carries from 100 to 350 parts per million of suspended matter, but during certain seasons of the year the water from Red River predominates to such an extent that the suspended matter will be as high as 3300 parts per million at Baton Rouge and 2500 parts per million at New Orleans. Compared with waters on Northern and Southern Lines all waters on Western Lines are poor, being highly mineralized, or as it is commonly expressed "hard waters." This is particularly true of the waters of Iowa and Northern Illinois.

Although Illinois waters may not be classed as among the best boiler waters the question of quantity has been a more serious problem than that of quality, particularly on the Illinois, St. Louis, Indiana and Wisconsin Divisions, the mileage of these operating divisions being practically all within the State of Illinois. On the

Illinois Division lying wholly within the State of Illinois and consisting of 416 miles of track and 22 water stations, 50 per cent of the water stations are supplied by wells, 25 per cent by streams and 25 per cent by reservoirs. There is a wide variation in the quality of water from wells, although all are rather high in carbonates. The waters from streams vary according to the seasons, but may be classed as fair boiler waters. The waters from reservoirs are, of course, all good waters.

On the St. Louis Division, also wholly within the State of Illinois and comprising 471 miles and 35 water stations, 60 per cent of the water used is from streams, 25 per cent from reservoirs and 15 per cent from wells. The well waters on this division are of poor quality with the single exception of the wells at Mounds. The surface waters are of fairly good quality except where they are contaminated by industrial wastes, especially mine wastes which are discharged into the streams. This is particularly true of the Big Muddy River supplying the Carbondale, Texas Junction and Sand Ridge water stations.

The water from the Big Muddy Carbondale is probably the most variable water on the system, ranging from a fairly good boiler water at flood stage to a very bad water at low stages of the river. This water is high in sulphates and very corrosive when the river is low owing to the high percentage of mine water present. All water used at Carbondale is treated in a complete lime and soda ash treating plant. Conditions on the Indiana, Springfield and Wisconsin Divisions, practically all of which are within the State of Illinois, are very similar to those on the Illinois and St. Louis Divisions.

There are 136 water stations located in Illinois handling annually 6,900,000,000 gallons of water. A total of 1,012,900,000 gallons of water is completely treated with lime and soda ash at thirteen water stations and treatment in the form of compound is applied to the water at fifteen other stations. Thus, 23 per cent, or 1,542,900,000 gallons of water, is treated before delivery to locomotives in some form or other, while compound is applied direct to tenders of locomotives at a number of engine terminals.

The first water treating plant on the Illinois Central was built in 1900 and at intervals since other installations have been made, until at the present time we have a total of 34 complete water treating plants in service. Three adjoining engine districts extending from Freeport, Illinois to Omaha, Nebraska, a distance of over 400 miles,

are now completely equipped with lime and soda softeners, and the two districts between Freeport and Clinton, Illinois, are also equipped with lime soda softeners. A locomotive could run from Decatur, Illinois to Omaha, Nebraska using treated water only, as every station in this stretch of 584 miles is equipped with complete lime and soda water softening plants.

The benefits from the treatment of boiler waters on the Illinois Central have been many and substantial while the intangible nature of some of the effects of the water treatment and the scattered location of some of the plants have made it impossible to compute the value of all treatment directly.

The figures for 1925 show that in treating 1,875,007,000 gallons of water, ranging from 9 to 56 grains per gallon hardness, the 34 complete lime and soda plants in service, representing an investment of \$670,000, removed 3,699,293 pounds of scale forming matter from the water treated. Using the figures of the Water Service Committee of the American Railway Engineering Association and after deducting for the cost of operation and maintenance, interest and depreciation on plant, the water softening plants show a net saving of \$311,353.59 per annum, or 46 per cent annual earning on the investment. This saving is limited to the value of reductions effected in the amount of fuel required by locomotives, flue renewals, calking and other running repairs and the time lost by locomotives while under repairs which might be attributed to water conditions. No figures are available from the standpoint of improved train operation, except perhaps the statement that the average performance of locomotives during the past five years has been over 2,000,000 miles per engine failure over the system and more than 5,000,000 miles in treated water territory, a performance considerably greater than that during the period prior to the establishment of water treating facilities by engine districts. The values due to improved locomotive operation, train service, etc., are of an intangible nature. If they were included they would probably equal the direct saving shown above.

The Illinois Central has what is believed to be the oldest Water Service Department of any road, as this department was organized nearly thirty-five years ago. The department is headed by a Superintendent of Water Service reporting jointly to the Chief Engineer and Engineer Maintenance of Way. Aside from the Chief Clerk and office force there are two inspectors on the staff of Superintendent

Water Service and the various foremen of the system construction outfits which are constantly maintained for construction and repair work. Two chemists also work in conjunction with the Superintendent of Water Services, although they report directly to Engineer of Tests.

On each operating division a Supervisor Water Service reports directly to the division maintenance officer and indirectly also to the Superintendent Water Service. This Supervisor Water Service directs the work of the repairmen, pumpers, treating plant attendants and the foremen of the division water supply gangs.

The authority of the Superintendent Water Service extends to all matters pertaining to water service of whatever nature. He checks and approves all estimates made for water service expenditures from any source and either makes or approves all recommendations before work is authorized. In addition all maintenance work is carried on under the supervision of the department, usually under the immediate direction of the division supervisors, and all requisitions for material required for water service other than incidental repairs supplied by the division stores, are secured upon requisition of the Superintendent Water Service. More than 500 persons are constantly employed in the operation and maintenance of pumping stations and other water facilities.

THE RAILWAY WATER SERVICE INSPECTOR¹

By J. P. HANLEY²

The speaker occupies the position of Water Service Inspector on the Illinois Central System, and his duties and work were thought of sufficient possible interest to call for an explanation at the present meeting.

When I first received Mr. Habermeyer's invitation I did not share his optimism about the matter, but later decided that I would accept for the Illinois Central and I are both long established citizens of this great State and are deeply interested in its water supply possibilities. We have a friendly feeling for and are in many instances customers of the public and privately operated water interests represented in this section.

The Railway System that employs me extends from Sioux Falls, South Dakota to Gulfport, Mississippi and New Orleans, Louisiana, and operates 339 water supply stations between these widely separated points. To assist in looking after these facilities it employs the water service inspector who reports to the Superintendent of Water Service and assists him in office work, field inspections, the supervision of divisional forces and such contractors as may from time to time be employed.

OFFICE WORK

The office work largely consists of making and checking cost estimates for proposed work and assembling current statistics to show various water service operating results, some of which are as follows:

1. Maintenance cost of water stations by divisions.
2. Tentative program for maintenance work for the ensuing year, listed by divisions, stations and months.
3. Gallons of water pumped per unit of one man hour listed by divisions.
4. Operating results of water softening plants and the estimated benefits derived from them based on the American Railway Engineering Association

¹ Presented before the Illinois Section meeting, March 24, 1926.

² Illinois Central Railway System, Chicago, Ill.

formula of 13 cents per pound for incrusting solids removed from boiler feed water.

5. Cost of water for freight, passenger and switching service based on the units of 1000 gross ton miles, 100 passenger train miles and one switch engine mile respectively, listed by divisions and compared.

6. Cost, amount and kind of coal used at pumping stations listed by divisions and compared.

7. Increase or decrease in bills for city water purchased at the principal stations using this source of supply.

FIELD WORK—MAINTENANCE

Our system has 17 operating divisions and the water service facilities on these divisions are for the most part in direct charge of an officer known as Water Service Supervisor, who has charge of repairmen, laborers and pump engineers.

The water inspector maintains close relations with each supervisor making inspection trips over the division with him, and discussing all conditions affecting the reliability and economy of the service at each station and assisting him in making estimates and recommendations for improvements where the conditions seem to warrant or justify the expense. This arrangement benefits the inspector by keeping him informed by first hand information of nearly all conditions existing. It gives the division officer the benefit of a consulting service arising from a wider field and in which, in many instances, a direct precedent is available for the items discussed. It benefits the Company by preventing excessive or insufficient recommendations and by giving a double check on many items of expense or trouble that might otherwise prevail.

When traveling over the divisions the inspector also makes inspections of pumping machinery, buildings, water tanks, water columns and similar items on a prescribed form which is submitted to the Superintendent and his attention called to any conditions that need immediate attention, or which are not being handled properly by the division.

FIELD WORK—CONSTRUCTION

When new construction work is authorized the inspector, under the direction of the Superintendent, writes the specifications for it and assembles the necessary drawings required, and keeps in touch with the construction inspector and contractor to whom the work is

assigned, to see that it is installed as specified and that the contractor's estimates are properly rendered.

Where unusual improvements, changes or operating trouble are proposed or experienced the Inspector usually goes to the location and by inspection and conference with the Division Officers investigates the matter fully and makes a detailed report to the Superintendent showing the conditions existing and recommending what should be done to correct them, if they cannot be solved on the ground at the time of the investigation.

PROPORTIONING CONCRETE BY WATER: CEMENT RATIO¹

By W. C. MABEE²

We have been so long accustomed to seeing concrete flowing down chutes with a sea of water floating it along that it appeared somewhat revolutionary to be told that this procedure was all wrong. We had believed that the quantity of cement employed was the governing factor in proportioning concrete for strength and paid little or no regard to the quantity of water used. Whereas we now learn that we were drowning our concrete and wasting cement without getting the added strength which the added cement was supposed to contribute. It was somewhat of a shock to learn that the given strength could be obtained with less cement, by simply reducing the quantity of water, or, in other words, by changing the water-cement ratio.

In fact, we had given little or no consideration to the amount of water being used; as long as we kept our proportion of cement to aggregate constant, we were quite sure we had done all that was necessary to secure a uniform product.

We now learn that the strength of concrete is absolutely fixed by the water-ratio, with the aggregate acting merely as a filler, so to speak, to simply add bulk to the cement paste or glue, and that any water in excess of that required to hydrate the cement and produce a workable mix of concrete reduces its strength. The ratio of water to cement called the "water-ratio theory" was developed as a result of research work with concrete materials at the laboratories of the Lewis Institute, Chicago, coöperating with the Portland Cement Association.

It has long been known that the size and grading of aggregate affect the strength of concrete, but it remained for these experiments to demonstrate that the influence of these factors was controlled largely by the effect they had upon the quantity of water used in the mix.

¹ Presented before the Indiana Section meeting, March 25, 1926.

² Assistant Chief Engineer, Indianapolis Water Company, Indianapolis, Indiana.

It was found that the higher the ratio of water used the weaker the concrete would be, without regard particularly to the quantity of coarse and fine aggregate employed.

As a measure of this strength, the slump test was devised and while the slump test is not an accurate indication of concrete strength it is the best index yet found.

The concrete giving the least slump or the driest workable mix, indicates the greatest strength and the most economical use of the materials entering into the concrete; but the degree of plasticity or workability, as it is called, must ever be suited to the character of the work in hand.

It is now possible for the engineers to proportion concrete by calculation, the potential strength being fixed by the water-cement ratio, influenced in the mix by the grading of coarse and fine aggregates and the workability of the concrete.

The actual or final strength of the concrete so calculated is affected by its age, the length of time in mixing, the method of curing, the temperature during which it was made and cured and the degree of impurities in the aggregate.

Methods of field control have been devised, the purpose of which is uniformity of product and dependability of results; this involves tests for quality and cleanliness of aggregates, percentage of moisture in the aggregates and the bulking resulting from this moisture and the determination of the grading, expressed in percentages of the coarse and fine aggregates by sieve analysis. All of these field tests have been rendered quite simple and can readily be made by an intelligent inspector on the job.

Many of our larger contractors are now proportioning and testing their concrete in this manner and are having their inspectors and field engineers report daily analysis of aggregate, make slump tests from samples of concrete actually going into the work and are even having compression tests made in laboratories from cylinders prepared from these samples.

In this manner a careful record is kept to guide them in designing and maintaining concrete mixes of uniform strength.

Along with the scientific proportioning of concrete and the advance in the art, there is a growing tendency among structural designers to use higher working stresses for bar steel in reinforced concrete. Factors based upon ultimate strength have given way to "Margins of Strength" based upon the yield point or service strength of steel.

Values of 18,000 or even 20,000 pounds per square inch are now considered as amply conservative by many leading authorities in place of the time honored stress of 16,000 pounds per square inch.

We also observe the tendency among engineers to require more exacting tests upon the materials which enter into concrete, and we find them insisting upon batch mixers equipped with water measuring devices, and timing devices and such refinements as inundaters, all of which tends towards producing a more dependable and uniform product.

There is now much more coring of pavements and laboratory testing of specimens than formerly. Engineers are now able to calculate the strength of concrete with assurance that the results will be within reasonable prescribed limits. To the engineer engaged in water works practice, one of the most vital considerations is impermeability. He is chiefly concerned in producing concrete of such density that it is impervious to water, and he knows that the degree of water tightness will depend upon the richness of the mix in cement, the suitability of the aggregates, the quantity of water used and the care with which the concrete is placed in the forms. Much depends upon the puddling or churning of the concrete in the forms as it is being deposited, if honeycomb pockets of aggregate are to be avoided, and he is well aware of the fact that an excess of water seriously affects permeability of concrete.

In work of any magnitude, consideration must be given to the control of cracks in concrete structures due to the forces of expansion and contraction, which cracks will occur regardless of the strength of impermeability of the concrete. These cracks can be localized and made water-tight by the insertion of suitable metal baffles or cut-off plates at certain intervals or in the day joints, or they can be quite effectively distributed by the use of sufficient steel bars uniformly placed in the faces of the work, using keyways in adjoining sections and coating the joinings with rich mortar, after having cleaned them thoroughly. The writer employs $\frac{1}{16}$ of 1 per cent for this purpose.

Thin sections of concrete require a richer concrete than do heavier ones. Plastering as a medium for waterproofing is a dubious expedient and in the writer's opinion should not be resorted to as a general practice, although there may be exceptions. It will be found more economical to proportion the concrete richer in cement and dispense with the plaster; it is false economy to skimp in the use of cement in structures designed to hold water.

The important consideration in the design of concrete for uniform impermeability as for uniform strength is not so much in the grading of the aggregates as it is in the fixing of the proper water-cement ratio and holding that ratio constant even to the extent of taking into the consideration the moisture in the aggregates, then adding good sound coarse and fine aggregate in sufficient quantity to make the resultant mix work smoothly and flow freely into the forms and around the reinforcing bars, applying sufficient agitation to insure positive distribution of all the materials.

The consideration of next importance is the proper timing of the mixing, from one and one-half to two minutes is good practice, and finally the protection and care of the finished product; by this is meant keeping the concrete moist for a week or ten days to avoid evaporation of the mixing water and consequent loss of strength. It has been found that proper attention to this detail alone increases the strength of concrete 65 per cent.

Floors can be kept damp by covering with sand and wetting frequently, vertical surfaces by draping burlap or canvas over the walls and sprinkling with a hose several times a day. Flat slab reservoir construction can be flooded to a depth of an inch or so by placing a slight ridge of mortar around the margin of the day's work. This is very effective in the hot dry days of midsummer, when such work is usually done. Checking and cracking of the surface is also reduced to a minimum by this expedient.

A little longer time in mixing pays big dividends in strength, in impermeability and in workability. Speeding up the mixer in the hope of increasing the output may actually produce negative results.

Increasing the time of mixing from one minute to two minutes will yield an increase of strength of 10 per cent and one to five will give 15 per cent.

One of the most interesting facts developed by students of concrete phenomena is that the strength of concrete increases as the logarithm of its age.

The writer only recently had occasion to cut into concrete that he had seen built over twenty years ago and it certainly showed every indication of having increased in strength.

In conclusion, it can be said that the engineers of Indiana are becoming more and more familiar with the method of proportioning concrete by the "water-cement ratio" theory and are putting this knowledge into their daily practice.

Their slogan should be: "Less water in mixing—more water in curing."

DISCUSSION

J. W. KELLY:³ Practical use has been made of the water cement ratio on almost one hundred concrete jobs. These range in size from small structures to public highways, large bridges and dams. It has been found that the proper water ratio for any strength and quality of concrete desired can be obtained by simple methods not radically different from our past practice on concrete work.

The three things entering into a concrete mix which are under the control of the mixer operator are, (1) the relative richness of the mix, or amount of cement, (2) the relative coarseness of the aggregate, or the proportion of pebbles to sand, and (3) the relative plasticity of the mix or what is more usually termed the workability. Each of these influence the amount of water required to obtain the plastic mix demanded by placing, finishing, etc. The above water requirements can be readily determined and the concrete proportions expressed in terms convenient to the man at the mixer.

The effort as regards strength is to use richer mixes, minimum amounts of sand, and drier mixtures, since these tend toward stronger concrete. The effort from a standpoint of economy, however, is to use lean mixes, since aggregates cost less than cement. For concrete of the same strength, leaner mixes can be obtained by using minimum amounts of sand and by using drier mixtures as before. The proper balance of these three factors constitutes the design of a mix.

One point that must not be overlooked in designing for concrete of certain compressive strengths is the waterproofness of the concrete. Richer mixes are required for waterproofness than may be called for by strength requirements above. This can be met by designing concretes of higher strength; it being usually considered that concretes of 3000 pounds strength or better are waterproof.

Practical men want to know (1) how much cement to use (2) how much sand is the best proportion to the pebbles, and (3) how dry can the mixture be and still work into place satisfactorily.

There are two methods of arriving at the proportions desired. One

³ Engineer, Portland Cement Association, Chicago, Illinois.

is by direct trial, using different proportions (but keeping the same water ratio) and judging by eye or by test which combination gives the best mix. Intelligently handled, this is a satisfactory method of proportioning concrete; otherwise it is little better than our arbitrary schemes of the past.

The method of calculating the ideal proportions for any job has been simplified until it calls for only a little study and a very little arithmetic. This method is described in a booklet published by the Portland Cement Association entitled, "Design and Control of Concrete Mixtures." Briefly, the method is as follows:

1. The strength desired and the allowable plasticity of concrete are decided upon for the job under consideration.

2. From a chart prepared by the Structural Materials Research Laboratory and based on the experience of many thousands of tests, the amounts of cement and of "mixed" aggregate are taken; this determines the mix.

3. Small samples of the sand and pebbles are passed through a set of sieves, and the relative coarseness of the particles of each determined by a simple calculation. This enables us to calculate the percentage of sand which must be employed to give us the ideal grading of "mixed" aggregate.

4. When the percentage of sand is known, the "mixed" aggregate can be expressed in terms of the separate aggregates, i.e., sand and pebbles.

5. Since the foregoing measurements have been made on samples which have been dried to obtain uniform results, the proportions obtained above must be corrected for the bulking effect of moisture. This involves measuring the water in a sample of each aggregate as it normally comes to the work, and determining the relation between a cubic foot of dry aggregate and an equal amount of the damp material.

These calculations enable the man at the mixer to measure definitely the proper amounts of cement, sand, and pebbles and know he is getting the proper water ratio and strength.

The strength of concrete as originally proportioned may be maintained on the job even if the aggregates change as the job progresses. Occasional tests for water in the aggregate enable us to compensate for variations in bulking. Occasional sieve tests detect any considerable changes in the grading of the aggregate, and the proportions may be corrected accordingly. The workability of the concrete is

regulated by the slump test, a simple field test which gives us a relatively good idea of the water used in the mixture.

Water-ratio proportioning of concrete has proven so simple and practical that it is being generally adopted for all classes of work. The advantage of knowing definitely what kind of concrete we are getting, and knowing that the most economical proportions are being used, have outweighed our natural reluctance to adopt new ideas.

ABSTRACTS OF WATER WORKS LITERATURE

FRANK HANNAN

Key: American Journal of Public Health, 12: 1, 16, January, 1922. The figure 12 refers to the volume, 1 to the number of the issue, and 16 to the page of the Journal.

Equations for Determination of Pressure Loss in Water Pipes. P. BRINKHAUS. Gas und Wasserfach, 69: 9 and 10, 165-168, 189-192, February 27, March 6, 1926. Equation for loss of head by water flowing through pipes is developed; $h/l = cv^2/D$ where h = loss of head, l = length of pipe, v = mean velocity, D = internal diameter of pipe. Mean velocity of 1 meter per second is applied in formula. Fundamental equation is probably correct although equations which have been developed for finding value of c are almost useless. Constant depends mainly on diameter of pipe while velocity of water has no great influence. Values of c by Biel and Langsehen have undoubtedly been determined with the greatest care.—W. U. Gallaher.

Corrosion Due to Magnesium and Calcium Salts. D. C. CARMICHAEL. Power Plant Engineering, 30: 7, 41, April 1, 1926. Chlorides and nitrates of calcium and magnesium decompose under boiler conditions to form hydrochloric and nitric acids which subsequently corrode boiler surfaces. Corroded area may be covered with scale making it hard to detect. Sulfate of magnesium in presence of chlorides forms chloride of magnesium which on secondary decomposition forms corrosive acid.—W. U. Gallaher.

Comparative Studies on the Oxidizability of Water According to the Kubel-Tiemann Procedure and the Determination of Chlorine Absorption. K. KEISER. Gas und Wasserfach, 69: 3 and 4, 41-43, 65-69, January 16 and 23, 1926. Author traces history of the determination of chlorine absorption capacity of water. In determining organic substances in water free from albuminous material, the permanganate method according to Kubel can be used just as well as the chlorine index or number according to Froboese. On the other hand, organic content of a sewage and waste polluted stream can only be determined by means of chlorine absorption capacity. Before the chlorination of the raw (Elbe) water, permanganate consumed by water from a fresh filter was much greater than by that from one long in use. After prechlorination, permanganate consuming capacities of waters from fresh and old filters have been approximately the same.—W. U. Gallaher.

Filter for Tubular Wells. K. MEERBACH. Gas und Wasserfach, 69: 1, 13, January 2, 1926. A steel tube with perforations is placed in well at water

bearing strata. A special suction head, attached to end of suction pipe can be raised and lowered as desired. Water is sucked through the strainer, carrying with it the fine sand which has clogged the well.—*W. U. Gallagher.*

Essentials of Correct Boiler Feed Water Treatment. R. E. HALL. *Power Plant Engineering*, 30: 5, 327, March 1, 1926. The standard treatment for boiler feed water must be ruled by conditions inside boiler instead of by degrees of hardness as measured outside. "The two major factors to be considered in prevention of scale formation on the evaporating surfaces are operating pressure and sulfate concentration in the boiler water." Sodium carbonate and sodium phosphate are the most feasible reagents to use for prevention of hard sulfate scale. The correct dosage of either substance may be calculated by formulae which introduce a constant K for each operating pressure. Phosphate is especially used to avoid calcium carbonate incrustation and to cut down concentration of hydroxide resulting from carbonate decomposition. Scaling in preheaters may be prevented by removal of bicarbonates. Presence of hydroxyl ions serves to remedy corrosion. Air may be removed by heaters, or deaerators, and carbon dioxide may be avoided by removal of carbonates from feed water.—*W. U. Gallagher.*

Vacuum System Gives Steady Water Flow. J. N. WILLIAMS. *Power Plant Engineering*, 30: 3, 337, March 1, 1926. Tank with screen chamber inserted in suction line of pump. Tank is kept full with vacuum pump so that the main pump never loses its prime.—*W. U. Gallagher.*

The Work of the Sanitary Water Board. C. H. MINER and W. L. STEYENSON. *The Listening Post* (Pennsylvania Dept. of Health), 4: 34, 4, January, 1926. Sanitary Water Board is charged with administration of anti-stream pollution laws and clothed with investigatory powers. Board recognizes that highest use of water resources is for public water supplies, and thereafter generally as follows: for conveyance of sewage and industrial wastes, after suitable treatment; for manufacturing, industry, power, and agriculture; for navigation.—*G. C. Houser.*

Effect of Water Supply on Typhoid Rate. F. E. W. *Public Health News* (New Jersey Dept. of Health), 11: 2-3, 65, January-February, 1926. At Franklin, N. J., through negligence, polluted river water was admitted to mains carrying treated water, and an epidemic of typhoid fever resulted which increased incidence of the disease from less than one case to nearly 30 cases per 1000. Two similar epidemics have occurred at Gloucester. With installation of continuous disinfection at Trenton, typhoid rate dropped immediately to a low figure.—*G. C. Houser.*

Fifteen Cases of Typhoid in One Family. Anon. *Health Bulletin* (North Carolina State Board of Health), 41: 2, 13, February, 1926. At Rockingham, N. C., 15 members of a colored family were stricken with typhoid fever, two cases proving fatal. The family did not use city water, and when their well went dry the housewife took her clothes to a creek to wash. One of the chil-

dren contracted typhoid by playing in the water, which is polluted with Rockingham sewage, and the disease spread through the household.—*G. C. Houser.*

Dug, Drilled, and Driven Wells. C. D. GROSS and H. F. FERGUSON. *Illinois Health News*, 12: 2, 52, February, 1926. Well should be located so that drainage will be away from it. Privy vaults should be at least 50 feet, and cesspools at least 75 feet, from well. Sewers or sink drains passing within 50 feet should be constructed of cast-iron pipe, or of glazed tile with cemented joints. Construction details are given for three kinds of wells.—*G. C. Houser.*

Florida Waters. E. L. FILBY. *Health Notes* (Florida State Board of Health), 18: 2, 24, February, 1926. Recently the United States Geological Survey has completed a quantitative mineralogical survey of the well waters and springs of state. The waters are tested for silica, calcium, iron, magnesium, sodium, and potassium; also for the content of bicarbonate, carbonate, sulphate, chloride, and nitrate; for hardness and for total solids.—*G. C. Houser.*

Operation of Connecticut Indoor Swimming Pools. C. L. POOL. *Connecticut Health Bulletin*, 40: 2, 37, February, 1926. During winter of 1925, Connecticut State Department of Health made its first detailed survey of the 41 pools operating in state. This article presents some observations resulting from survey. To keep water in pool in proper condition, two things are necessary: first, water must be kept free from visible suspended matter, and second, it must be continuously disinfected. For the first requirement, cleaning and refiltration or frequent refilling is the standardized practice, and for the second, chlorination in some form appears indispensable.—*G. C. Houser.*

Many School Water Supplies Found Unsatisfactory. J. E. B. *Public Health News* (New Jersey Dept. of Health), 11: 4, 92, March, 1926. More than half the 740 school water supplies recently examined by State Department of Health show evidence of contamination and must be classified as unsuitable for drinking purposes. Wells, springs, and cisterns were included in this survey, embracing all types of water used in schools not receiving water from an approved public system.—*G. C. Houser.*

Estimating Fabricated Pipe Costs. IRA A. BUTCHER. *Power*, 63: 12, 443, March 23, 1926. Author gives figures on cost of cutting and threading pipe of various sizes; also of flanges, lap joints, and pipe bending. Profitable plan for laying out piping is discussed.—*Aug. G. Nolle.*

How a Direct-Current Motor Operates. A. A. FREDERICKS. *Power*, 63: 12, 452, March 23, 1926.—*Aug. G. Nolle.*

Philadelphia's Water Supply Failure Investigated by Ledoux. *Power*, 63: 12, 468, March 23, 1926. Report submitted is exhaustive and covers the Shawmont, Roxborough, and Torresdale Plants. Summary of causes of failure and recommendations made are likewise included.—*Aug. G. Nolle.*

Relative Merits of Different Methods of Deep-Well Pumping. Power, 63: 13, 503, March 30, 1926. From report of committee on water service of American Railway Engineering Association at annual convention in Chicago, March 9, 1926. Most common types of equipment are the deep-well reciprocating pump, the deep-well centrifugal, or turbine, pump, and the air lift. Deep-well pumps consist primarily of three parts: the water end, the power end, and the transmission line, or driving mechanism. In comparing relative merits, consideration should be given to following features: character of water; capacity of source supply; pumpage required; pumping head; first cost of complete installation of equipment; length of useful life; reliability; flexibility; efficiency; and cost of operation. When water in well contains appreciable amount of sand or gritty material, air-lift pump will give best, and reciprocating pump, poorest service. Where yield of well is relatively small and stratum moderately deep, reciprocating pump is most desirable. If stratum is capable of delivering large volume of water and depth does not exceed 150 to 200 feet, turbine pump will produce most economically largest volume of water. In general, first cost of turbine-type pump is highest and of air-lift pump, including compressor, but not prime mover, lowest. As to reliability and length of useful life, type and fitness of pump for service required are large determining factors. All three types of pump are flexible to a certain extent. For protection against fire, turbine-type is most desirable, as it furnishes a large quantity of water without pulsation. In general, efficiency of reciprocating pump will reach 80 per cent under favorable conditions; that of turbine pump, 65 per cent, and of air-lift pump, 35 per cent. Under average conditions, maintenance cost of air-lift systems will be lowest, and of reciprocating systems highest. To insure reliability and greatest overall economy, individual conditions should be thoroughly considered and analyzed before choice of equipment is made.—*Aug. G. Nolte.*

Testing Polarity of Transformers. EDWARD SWAN. Power, 63: 14, 520, April 6, 1926. Methods of testing are illustrated and described.—*Aug. G. Nolte.*

Shipping Board Completes Tests on First of the Large Diesels on Order. Power, 63: 14, 524, April 6, 1926. Unit is 2900-h.p. double-acting two-cycle engine, designed and built by Worthington Pump and Machinery Corporation. Average fuel consumption for a 30-day run was 0.462 pound per brake horsepower-hour. Analysis of fuel oil used and complete record of test are given. Inspection of engine after the test showed very little wear.—*Aug. G. Nolte.*

Boiler Feed Pump Operates Against 1325 Pounds. Power, 63: 15, 559, April 13, 1926. Pump handles 150,000 pounds of water per hour at 250°F. It is a Worthington, 3-inch, eight-stage, double case turbine type, driven by a variable-speed slip-ring motor of special design. Stresses handled by using two casings, one inside the other, giving in effect a two-stage distribution of stresses. To seal inner casing from outer, specially constructed lead bull ring on cone joint is inserted. Other features of pump are described.—*Aug. G. Nolte.*

Novel Speed Control for Diesel Engines. E. J. KATES. *Power*, 63: 16, 596, April 20, 1926. The New York Central Railroad Diesel Pumping Plant near Selkirk, N. Y., supplies an exceedingly uneven demand for water. Diesel engines originally equipped with hand-controlled variable-speed governors arranged so that by turning handwheel governor spring tension was altered and speed could be set for anything from full speed down to half. Variations in water demand made this practise of regulation impossible. Setting engine for about three-quarter speed and depending on water relief valve on pump discharge to by-pass excess water when demand fell off and pressure rose was uneconomical. Consequently on automatic governing system was developed to maintain constant pressure on pipe line independently of water demand. Author illustrates and describes the new control system.—*Aug. G. Nolte.*

Lubrication of Electric Machinery. CLAIR L. KEENE. *Power*, 63: 17, 629, April 27, 1926. Importance of proper lubrication of electrical machines and of use of correctly selected oil is discussed.—*Aug. G. Nolte.*

America's Largest Four-Stroke-Cycle Diesel Ends Tests. *Power*, 63: 17, 640, April 27, 1926. The engine, together with its auxiliary, was run at full load for 30 days, after which a 10 per cent overload was carried for 6 hours. Power output was measured by a calibrated water brake. Combined fuel consumption of main and auxiliary engines was 0.409 pounds per brake horsepower-hour delivered at shaft of the 2700-h.p. unit. Fuel used during part of test was very heavy and had a sulphur content of 4.8 per cent. Principal dimensions of units are given in tabular form.—*Aug. G. Nolte.*

Explosion Hazards from the Use of Pulverized Coal at Industrial Plants. L. D. TRACY. *Power*, 63: 17, 652, April 27, 1926. This is an abstract of Bulletin 242 of United States Bureau of Mines. Pulverized coal in bulk is not explosive. It becomes dangerous only when stirred up into a cloud with proper proportion of air and brought into contact with an open flame or with body having temperature high enough to ignite it. In general, any coal retained on a 20-mesh screen does not enter into the propagation of an explosion. An unsuspected danger lurks in the dust from some types of heating furnaces. A number of actual explosive accidents are described fully in the bulletin. Danger exists in the drier and in the coal storage bin. To avoid danger, plant must be kept clean and free from accumulating coal dust. The bulletin closes with long list of concrete suggestions to promote safety.—*Aug. G. Nolte.*

Application and Operation of Diesel Engines. G. A. ADKINS and R. H. BACON. *Power*, 63: 17, 653, April 27, 1926. Abstract of paper presented before Gas and Oil Power Conference, Chicago, Illinois, April 21, 1926. In order to determine whether Diesel Engine will effect any substantial saving as compared with cost of purchased power or of steam power, it is necessary to analyze all factors that affect the cost under the particular load conditions. Authors take a typical load and show in general way how Diesel units may be fitted to this load and what probable cost of operation will be.—*Aug. G. Nolte.*

Greensboro Water Works Adds Turbine-Driven Pumps. Power, 63: 18, 681, May 4, 1926. Demand exceeding capacity of old water-works forced installation of newer and larger pumping units.—*Aug. G. Nolte.*

Some Practical Comments on Power-Plant Logs. WM. E. GRAY. Power, 61: 17, 643. April 28, 1925. Records kept should be simple, but reliable. Most common way is to record all readings directly on one ruled form: a system open to several objections. Another plan is to have pad of small sheets placed at each point where reading is to be taken; these are later entered on one composite record by man designated for that duty. Record of inspection and of repairs should be kept. Certain pieces of apparatus can be placed on a regular inspection schedule. Standard forms could be provided for boilers and superheaters, turbine pumps, reciprocating pumps, condensers, motors, etc.—*Aug. G. Nolte.*

Operation of Diesel Engines. R. HILDEBRAND. Power, 61: 17, 651, April 28, 1925. Inlet and Exhaust Valves are discussed.—*Aug. G. Nolte.*

Operating Results at Philo. Power, 61: 19, 720, May 12, 1925. Record of Ohio Power Company's Plant shows high station-operating efficiency. Each piece of apparatus chosen with view to operating at highest possible efficiency. Condensing water taken from old reconditioned canal by gravity. Low grade coal obtained at attractive prices and burned to give excellent results. Boilers have both economizers and preheaters necessitating use of induced-draft fans. Boiler make-up is taken from canal and passed through cold-water treatment system into storage tank. As required by boilers, water is put through quadruple-effect evaporator. Steam lines are made of seamless tubing. Turbines are arranged for reheating. Reheater equipped with safety device. Steam consumption reduced from 9.6 to 8.18 pounds per kilowatt-hour. Boiler operators are provided with all instruments needed to obtain best efficiency.—*Aug. G. Nolte.*

Operation of Diesel Engines. R. HILDEBRAND. Power, 61: 19, 735, May 12, 1925. Author discusses air starting valves and their care.—*Aug. G. Nolte.*

Questions and Answers. FRANKLIN VAN WINKLE. Power. Subjects as follow: 61: 17, 666, April 28, 1925. Incondensable Gases Impair Vacuum; Slip and Negative Slip of Pump; Jumping of Pump; Overheating of Boiler Heating Surfaces; Shortest Cutoff with D Slide Valve; Direction of Driving Horizontal Gear-Driven Pump; Determining Radius of Dished Head; Excessive Use of Soda Ash; Obtaining Given Cutoff with D Slide Valve; Better Drive Obtained With Inclined Belt. 61: 18, 705, May 5, 1925. Removal of Slag From Walls of Oil-Burning Furnace; Eccentric Piston Rings; Speeds of Single and Multi-Stage Turbines; Proximate Analysis Compared With Ultimate Analysis of Coal; Expansion of Copper Cylinder; Loop Due to Late Admission of Steam; Wrong Length of Hook Rod Gives Apparent Inequality of Laps for Equal Leads; Power Transmitted by Leather Belting; Measuring the Diameter of Wire Rope. 61: 19, 744, May 12, 1925. Curved Arms of Cast-

Iron Pulleys; Reducing Cost of Cooling Water; Thicker Fire Toward Bridge Wall; Efficiency of Triple-Riveted Butt and Double-Strap Joint; Number of Turns in Auto-Transformer Coils; Five-Ported Valve Seat of Duplex Pump. 61: 20, 801, May 19, 1925. Foaming and Priming; Boiler Corrosion from Good Water; Cause of Compressor's Low Temperature; Size of Header for Battery of Boilers; Friction of Steam Engine Practically Constant; Setting D Slide Valve Without Uncovering Steam Chest; Changing from Two-Wire to Three-Wire System.—Aug. G. Nolle.

The Applicability of Koser's Citrate Utilization Test to Sanitary Water Analysis in India. T. N. S. RAGHAVACHARI. Ind. J. Med. Res., July, 1926. (Advance proof.) Results of comparative tests of citrate utilization and other biochemical characteristics, including M.R. and V.P. tests, of large number of coliform organisms isolated from soil and water in India indicate that significance of citrate utilization in sanitary water analysis has yet to be established. Koser found that M.R. +, V.P. — types of lactose fermenters which occurred in soil free from human and animal pollution could be differentiated from M.R. +, V.P. — types from fecal sources by their ability to utilize citrate. Of 518 cultures from 54 samples of soil examined by author, 34 were M.R. +, V.P. — and 484 M.R. —, V.P. +, all of latter and 8 of former being citrate +. Of 1574 cultures derived from 158 samples of water collected from various locations in Madras Presidency, 67.3 per cent were of low ratio type and 32.7 of high ratio type, proportion being 69.9:30.1 for unfiltered water and 61.6:38.4 for filtered water. Only 8 of 407 low ratio strains from springs and wells were able to utilize citrate and none of 344 from rivers, lakes and impounding reservoirs developed in citrate medium. Forty-four out of 222 low ratio cultures from slow-sand-filtered water and 11 of 86 from mechanical filter effluents utilize citrate. None of citrate-utilizing low ratio organisms produced indol and conversely every indol producing lactose fermenter from both soil and water failed to utilize citrate. Classification of low ratio citrate-utilizing organisms as of non-fecal origin would have far-reaching effect in judging quality of supplies concerned, and would not correlate with scheme of Clemesha, depending on resistance of organisms to sunlight, which is basis of water bacteriology in India. *B. vesiculosus*, which is M.R. +, V.P. — and indol +, irrespective of source of culture, was found to be unable to utilize citrate. Presence of this class of organism exclusively has long been considered at King Institute as evidence of pollution at comparatively distant date and such waters have been passed as potable if otherwise satisfactory. Such supplies, on basis of citrate utilization, would be condemned as unfit for drinking purposes. Also, waters found to contain lactose fermenters of high ratio type in quantities as small as 0.01 cc. have been condemned owing to excessive bacterial pollution, whereas such supplies would be considered potable according to Koser's scheme, as M.R. and citrate tests would indicate absence of fecal contamination. Further studies along these lines are being conducted.—R. E. Thompson.

Iron Bacteria. A. C. SWINNERTON. Science, 63, 74, January 15, 1926. Occurrence is reported of *Leptothrix ochracea*, *Sirophyllum ferrugineum*, and

Gallionella ferruginea at Iron Spring near Mirror Lake in Yosemite National Park. Collections were made from small pools and seeps directly on black soil where scum was exposed to air partly protected from sunlight by foliage. *Gallionella* particularly has not been found previously in the open. Iron bacteria were also found in scum on springs at just above high tide level at foot of sea cliffs at Moss Beach, Calif.—*R. E. Thompson*.

History and Problems of Irrigation Development in the West. JOHN A. WIDTSOE. *Proc. Am. Soc. Civ. Eng.*, 52: 3, 396-402, March, 1926. Nine million acres of land in Western America were irrigated in 1909. Poor financial returns on investment made capital reluctant to engage in irrigation enterprises. Congress passed the Reclamation Act in 1902, and in the two decades following nearly \$150,000,000 was spent on construction of irrigation works. This brought about two million acres of land under the ditch. In 1920, total land being irrigated was about twenty million acres, and value of the crop harvested about \$760,000,000. Irrigation is a complex art, involving application of the best knowledge of agriculture, engineering, hydraulics, rural economics, and sociology.—*John R. Baylis*.

The Financing of Irrigation Developments by Private Capital. R. E. SHEPHERD. *Proc. Am. Soc. Civ. Eng.*, 52: 3, 303-10, March, 1926. The substance and conclusions are largely the result of experience in solving problems of the privately owned Twin Falls North Side Project. To secure required funds, the North Side and other near-by projects, covering about 450,000 acres of irrigated land, organized themselves into a quasi-municipal district, known as the American Falls Reservoir District. This district entered into a contract with the United States for building of reservoir. This arrangement has proved very satisfactory.—*John R. Baylis*.

Present Policy of the United States Bureau of Reclamation Regarding Land Settlement. ELWOOD MEAD. *Proc. Am. Soc. Civ. Eng.*, 52: 3, 411-15, March, 1926. The first conception of the Reclamation Act made it largely a matter of engineering and construction. It made no provision for organization of settlers or giving them aid in any manner. Combining cost of water right and development cost of farm, the settler is confronted with an expenditure of from \$200 to \$250 an acre before he grows a crop. On one project which has been in operation for fifteen years, where the soil is good and the water supply ample, half the land is unoccupied. Unless land prices are fixed in advance and a program of settlement decided on, the building of irrigation works will involve a heavy loss.—*John R. Baylis*.

Land Settlement of Irrigation Projects. AUGUSTUS GRIFFIN. *Proc. Am. Soc. Civ. Eng.*, 52: 3, 416-22, March, 1926. It is necessary first of all to have the proper kind of settlers. On large projects it will take a number of years to complete settlement and it is desirable to settle it by units. Scattered settlement increases annual costs and hampers development of the social structure. New settlers must learn the climate, create a social structure of schools, churches, business centers, etc., study agricultural practices, and

learn to prepare land for irrigation and practice the art of irrigation. An irrigation system should be built and maintained for service.—*John R. Baylis.*

Irrigation Development Through Irrigation Districts. E. C. EATON and F. ADAMS. *Proc. Am. Soc. Civ. Eng.*, 52: 3, 422-33, March, 1926. Irrigation districts are found in all the 17 Western irrigation States except Kansas and Oklahoma. In 1921, 244 were operating, 37 under construction, and 159 in preliminary stages. The total area embraced, omitting those inactive, exceeds 11,000,000 acres. A few typical irrigation districts are briefly described. The ideal condition for the organization of an irrigation district is to find the enterprise already under way, although not adequately financed.—*John R. Baylis.*

Trend of Construction Cost of Certain Public Utilities. WILLIAM BREUER. *Proc. Am. Soc. Civ. Eng.*, 52: 3, 434-8, March, 1926. It was found that, since 1918, whether for a street railway, a gas, or an electric property, a power plant, or a distribution system, a sub-station, or a transmission line, and regardless of location or magnitude, the composite trend was substantially the same. The peak was in 1920. Comparing with 1924, the cost in 1914 was about one-half, and the peak in 1920 was about 25 per cent higher than in 1924.—*John R. Baylis.*

Multiple-Arch Dam at Gem Lake on Rush Creek, California. Discussion by F. W. SCHEIDENHELM. *Proc. Am. Soc. Civ. Eng.*, 52: 3, 457-67, March, 1926. The disintegration of the concrete is believed to be due to a combination of causes: percolating water, severe freezing alternating with thawing, and inferior concrete. Belief is that hollow concrete dams are permanent if concrete is good.—*John R. Baylis.*

Corrosion of Concrete. JOHN R. BAYLIS. *Proc. Am. Soc. Civ. Eng.*, 52: 4, 549-79, April, 1926. Portland cement does not form compounds insoluble in water corrosive to calcium carbonate. Finely ground hydrated portland cement gives off calcium hydroxide approximately to the point of calcium hydroxide saturation. The saturation equilibrium decreases by the addition of successive quantities of water, forming a curve that does not indicate definite high calcium compounds of silica. Porosity is a very important factor in determining the life of concrete exposed to water or to the weather. It largely governs the rate of diffusion of soluble compounds from the interior to the surface. If all surfaces of concrete particles are so close together that the oriented water layers unite throughout, there is little communication between the water in the interior and the outside surface. This is the ideal condition for resisting corrosion. A method of measuring the voids in concrete is given. It is suggested that the No. 8 sieve be the dividing line between fine and coarse aggregate. Changes taking place in concrete exposed to water or to the weather are usually the liberation of calcium hydroxide, and its combination with carbonic acid to form calcium carbonate. If the water is corrosive to calcium carbonate, it will be dissolved gradually. The gelatinous compounds of alumina and silica remaining after the calcium has been dissolved greatly aid in decreasing the solution rate. Moisture evaporating from a concrete surface

tends to concentrate destructive compounds, if present, at various points. The surface of most of the concrete exposed to water corrosive to calcium carbonate should be waterproofed.—*John R. Baylis.*

Interstate Water Problems and Their Solution. M. C. HINDERLIDER and R. I. MEEKER. *Proc. Am. Soc. Civ. Eng.*, 52: 4, 597-613, April, 1926. Growth and future prosperity of the arid states rest primarily upon efficient use of waters of Western rivers. Use and re-use of these waters, from their source down, are imperative to self-preservation of the states and the welfare of the nation. Water consumption in the Western United States has attained that stage of development wherein such uses in one or more states frequently give rise to fear of encroachment on the use in adjoining states. Under such conditions, wherein the sovereignties of two or more states, or nations, come into conflict, it is readily seen that there may be fruitful ground for trouble. The problem is one between states equal in power and with equal rights of self-preservation, and not one between mere private users whose rights are derived from their respective states. Due to the physical conditions present in practically all major drainage basins, demands are frequently made on the water supply of one state for use in another state or in another river basin. The purpose of interstate water compacts is to settle the title to river flow between or among the states claiming a river as a common resource. In making pact adjustments, the underlying principles have been to ascertain and define the relative needs and rights as between the states interested and to safeguard future development against unnecessary delays and the unsettled status of title, and against wasteful and protracted litigation. The states have the same power (with the consent of Congress) to enter into compacts with each other on all matters not delegated to the Federal Government, as independent nations have to make treaties.—*John R. Baylis.*

Stream Regulation with Reference to Irrigation and Power. J. C. STEVENS. *Proc. Am. Soc. Civ. Eng.*, 52: 4, 614-26, April, 1926. Regulation of the water of a stream to render it available for both power and irrigation is largely a local problem. Power and irrigation demands are usually so widely different that decision must be reached as to which use shall be given preference. Irrigation is generally recognized as the superior use of water. Regulation for power conserves surplus waters for use throughout the entire year, whereas regulation for agriculture conserves the surplus for use during about one-half the year. Uniformity of stream flow is a valuable characteristic in power development, but loses much of that value when entire supply is devoted to agriculture.—*John R. Baylis.*

Analysis of Concrete Arch Systems. C. S. WHITNEY. *Proc. Am. Soc. Civ. Eng.*, 52: 5, 836-78, May, 1926. The author presents a simple method for analyzing a system composed of two arch spans with an elastic pier. It consists in replacing a single eccentric load by two pairs of symmetrically placed loads which have the single load for their resultant. The analysis of the structure under this new loading is considerably simpler because of the symmetry. An easily applied approximate method is also given for the analysis of a system

of any number of spans. The article contains 13 tables, 43 equations, and 22 figures.—*John R. Baylis.*

Apparatus for Purifying and Treating Water, More Particularly Feed-Water for Boilers. C. HAYTHORPE. E. P. 220,189, 3.10.23. Chem. and Ind., 43: B 804, October 3, 1924.—*A. M. Buswell.*

Removal of Dissolved Organic Matter from Surface Drinking Water. O. PFEIFFER. Gas.- u. Wasserfach, 67: 470-472, 1924, Chem. and Ind. 43: B 803, October 3, 1924. Elbe river water was treated with 0.3 g. of chlorine per cubic meter, added in the form of aqueous solution just before water entered rapid sand filter. Potability of the water both as regards appearance and taste was rapidly improved and maintained at a high level. T. S. W.—*A. M. Buswell.*

Treatment of Natural Base-Exchange Zeolite-Like Materials. E. B. HIGGINS. E. P. 224,506, 10.9.24 Chem. and Ind., 45: 174, March 5, 1926. Clay-like impurities are rapidly separated from a base-exchange material for water-softening, e.g., glauconite, by subjecting it to a peptising and hydraulic grading process in one or more columns of upwardly-flowing liquid, e.g., a faintly alkaline solution (0.5-1 pound of caustic soda per ton) or a solution of common salt. The speed of the column is regulated so that the finer solid particles flow upward out of the apparatus and the coarser ones settle to the bottom and the speed of the liquid increases in succeeding columns. D. G. Hewer.—*A. M. Buswell.*

Water Softening Apparatus. Wayne Tank and Pump Co. Assees. of W. J. HUGHES (E. P. 231,818, 5.8.24. Conv., 4.4.24). Chem. and Ind., 44: B 1010, December 25, 1925. Apparatus consists of a container for the water-softening material (e.g., zeolites) in conjunction with another chamber through which hard water circulates normally, but through which regenerating solution may be added during regeneration of the exhausted material after back-washing. A. G. P.—*A. M. Buswell.*

Method of Softening Water. A. R. BURNETTE, Assr. to A. R. Burnette Corp. (U. S. P. 1,553,067, 8.9.25. Appl., 17.4.22). Chem. and Ind., 44: B 1010, December 25, 1925. Water under a pressure of approximately 200 pounds per square inch is passed through a system wherein it is first raised in temperature, then brought to boiling point, filtered at that temperature, and finally brought into heat exchange relation with the incoming cold water. W. T. L.—*A. M. Buswell.*

Water Softening Apparatus (Using Zeolite). J. BRANDWOOD. E. P. 227,707, 22.5.24. Chem. and Ind. 44: B 226, April 3, 1926. A method is proposed to overcome the channelling which occurs in zeolite filters. The softener consists of four or more circular vertical filter packs. Each filter pack consists of a perforated iron cylinder surrounded by two further perforated concentric cylinders. The outer annular space is packed with sand and the

inner annular space with zeolite. The hard water flows through the sand, then through the zeolite and out through a hole in the bottom of the central cylinder, which is screwed into a plate forming the cover of a lower chamber for the softened water. M. B. D.—A. M. Buswell.

Filtration of Water with Membrane Filters. R. ZSIGMONDY. *Z. Hyg. u. Infekt-Krankh.*, 102: 97-108, 1924. *Chem. Zentr.*, 95: II, 524, 1924. *Chem. and Ind.*, 43: B 803, October 3, 1924. All injurious bacteria are retained by a filter which when tested under 4 atmospheres pressure allows no air to escape and the maximum size of the pores of which is, therefore, about 0.75μ . Slimy materials of unknown nature are often present in town water and interfere with filtration. These can be removed by kieselguhr or by ferric hydroxide gel produced by adding ferric chloride to the water, together with calcium carbonate if necessary. C. I.—A. M. Buswell.

Apparatus for Removal of Gases from Liquids (e.g., Air from Boiler Water). H. FOTHERGILL. E. P. 230,160, 1.12.23; cf. E. P. 171,757 and 196,064, J. 1922, 43 A; 1923, 571 A. *Chem. and Ind.*, 44: B 421, June 12, 1925. Air can be removed from boiler water by spraying the water against live steam and then allowing it to drop on to hot steam coils, whereupon flashing occurs and the remaining gases are completely liberated. The amount of steam required for flashing the water, when this method is used, corresponds to about 2.4 per cent of the weight of the water. M. B. D.—A. M. Buswell.

Apparatus for Degasifying Liquids (Removing Air from Boiler Feed Water). J. B. MACLEAN and J. A. AITON. E. P. 225,639, 18.10.23. *Chem. and Ind.*, 44: B 145, March 6, 1925. A method for removing air from boiler feed water which combines the methods of heating the water, while subjecting it to a reduced pressure, and of passing the water over iron plates, whereby the oxygen is removed by chemical action. M. B. D.—A. M. Buswell.

Dissolving Gases in Flowing Liquids, Especially in Processes of Water Purification. L. GARTZWEILER. G. P. 1,072,444, 18.1.21. *Chem. and Ind.*, 44: B 262, April 17, 1925. Gases such as chlorine and carbon dioxide are forced in the form of small bubbles into a stream of flowing water, such as waste water, which is to be purified by treatment with the gas, and solution of the gas is aided by bringing the mixture of water and gas bubbles in contact with horizontal or inclined baffles having rough, grooved, or ribbed surfaces. L. A. C.—A. M. Buswell.

NEW BOOKS

Water Purification Plants and Their Operation. MILTON F. STEIN. 3rd edition. John Wiley & Sons, New York. It is now seven years since the second edition of this work was issued and it is indeed unfortunate that the late Mr. Stein did not live to see the publication of the third edition. Progress in the purification and treatment of water supplies has resulted in radical changes of thought involving new and technical theories which, as the author

states, "while they have not yet influenced the essentials, promise to do so in the near future." Comparatively few changes appear in the text and in view of the excellent nature of the additional chapters dealing with biological, colloidal and physical chemistry, one might ask why certain chapters have not been brought up to date, particularly those relative to types of purification plants, coagulation and sedimentation, and the operating costs and data which include the figures for the years 1910-11. These latter figures are probably now out of date in view of the increased costs involved in construction, operation and costs of chemicals. Very valuable appendices have been added, these include the interpretation of bacteriological tests, the colloidal theory in water purification and the hydrogen-ion concentration. These appendices are right up to the minute, but are so highly technical that they may not serve the original purpose of the author in meeting the requirements of the non-technical operators of small plants. To technically trained workers the added sections will be welcome because they cover the subjects so lucidly and completely that they leave nothing to be desired. In chapter 3 small additions are made in chemical and physical tests, the iron determination being changed while the ortho-tolidin test for estimation of chlorine in water is given in full. Chapter 4 devoted to bacteriological tests of water still retains the phenolphthalein method for titration of media. The chapter on interpretation of tests contains an addition upon the confirmation of *B. coli* tests and includes a graph showing the allowable bacteria in filtered water. In this chapter the author lays particular stress upon the importance of determining if the gas formers in lactose broth are of fecal or non-fecal strains. Considerable additions are made to the chapter dealing with sterilization methods, the quantitative method of chlorine control as devised by Wolman being included. A large amount of space is devoted to methods and types of chlorine machines. In the text dealing with water softening a graph is added showing the effect of additional amounts of lime on the equilibrium conditions of the water being softened. The chapter devoted to filtration and general operation remains unchanged.

Additions are made to appendix B, certain standard solutions being added. Appendix E consists of a description of the numerical interpretation of bacterial tests, explains the proper methods of numerical interpretation, and points out certain conditions which must be met and certain limitations which must be submitted to. The methods given are based on the theory of statistics and probability, and include a discussion of the expected error, the standard deviation, application to the bacterial count and *B. coli* test based upon the examination of a single sample and repeated samples. The chapter devoted to the colloidal theory in water purification is comprehensive and complete. The colloidal theory is aptly defined as a recognition of an intermediate stage or phase between matter in suspension and matter in true solution. Some of the peculiar properties of colloids are given and an explanation of them made. The part played by colloids in water purification is fully covered, deductions based upon scientific facts are given explaining the theoretical reasons why trouble may be experienced in the production of coagulation in certain waters containing organic matter and vegetable color, with certain concentrations of hydroxides. In this appendix other subjects covered include the effect of

alkali on coagulation, the removing of color by coagulation and filtration and the removal of colloidal iron.

The final appendix is highly technical and deals with hydrogen-ion concentration in water purification. The text includes definitions of the terms used and an illustrated description of various apparatus for making the determination by electrometric-titration method. It is of interest to note that the author expresses no opinion as to the value of the hydrogen-ion concentration in water purification, confining himself to a description of the theory and apparatus involved. It is well known that in the latter years of his life he was unconvinced as to its practical value in water purification. In its application to water analysis he states, "it correlates the alkalinity and carbonic acid determinations, and gives an indirect method for determining organic acids which may be present." In the titration of bacteriological media the author thinks it is of doubtful value as a substitute for phenolphthalein titration, claiming that the changes wrought in the composition of the medium by the addition of strong corrective reagents may be more harmful to the bacteria than slight variations in pH. The relationship of aggressive carbon dioxide to corrosion is briefly dealt with, the author regarding the determination of H-ion concentration as a routine test of value in this connection. When this book was first published eleven years ago its success was immediate on account of its comprehensiveness and simplicity of language. The added information contained in the third edition makes it additionally valuable.—*Norman J. Howard.*